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MECHANICS LABORATORY PRACTICE

BY

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PREFACE.

This book has been prepared as an aid to the students of the various classes working in the Mechanics Laboratory.

It is obvious that a book of this nature cannot be exhaustive, but as far as possible description of the various machines along with the procedure and method of recording the results have been given in detail.

Although every care has been taken to eliminate errors in the text, yet it is highly probable that some few still remain and the Author will be indebted for information leading to their detection.

The Author is deeply indebted to The University of Travancore, The Principal and The Professors of The College of Engineering for the kind help they gave him at all times.

College of Engineering
Trivandrum, 1942.

S. RAJARAMAN.

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* * *

MECHANICS
LABORATORY PRACTICE

EXPERIMENT NO. 1.

Conditions of Equilibrium of a body under the action of three Forces.

Object of the Experiment. Determine under what conditions three forces passing through a point are in equilibrium.

Apparatus. Vertical board with pulleys, string and weights. (W_1 W_2, W_3).

Procedure. First adjust the pulleys to work freely. Attach a weight (alike or unlike) to each string as shown, and place a sheet of paper on the board behind the strings. Allow the point under action of the forces to come to rest, and carefully mark the three directions, by points on the paper· Note the force acting in each direction and remove the paper.

Set out to scale any one of the forces on the same paper, and add the remaining two as vectors. What is the result of this sum or combination of forces in equilibrium? Allowance should be made for friction and inaccuracy.

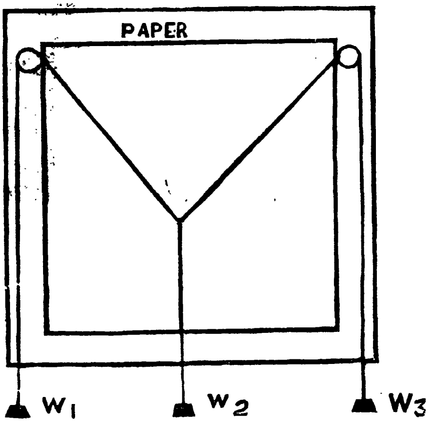


Fig. 1

Set out the same forces in some other order. Is the result the same?.

Alter the value of the forces and repeat the above.

What conclusions do you make as to the force diagram of three forces in equilibrium ?. Now place an unknown weight on one string and balance the system by known forces from the other strings. Using the knowledge gained above (That these three forces drawn to scale form a closed triangle) determine by construction the value of the unknown force. Check your answer by direct weighing.

Write shortly the conclusions you are led to by this experiment.

Ex.:—A load of 6 cwt. is suspended at the junction of two chains, one is inclined upwards at 45 degrees and the other at 30 degrees to the horizontal.

Determine the force acting in each chain.

EXPERIMENT NO. 2.

Conditions of equilibrium of a body acted upon by several forces passing through one point.

Object of the Experiment. Determine the conditions of equilibrium for the above "conditions".

Apparatus. A vertical board with several pulleys, weights and string as shown.

Procedure. First adjust the pulley to work freely. Now place a sheet of paper on the board behind the strings. Arrange say five forces to act at one point using pulleys and strings, so that the point comes to rest repeatedly in one place, when disturbed. Next mark carefully on the paper the direction of all forces acting. (A point at the centre and under each string a point near the pulley is sufficient.) Note the values of W_1, W_2, W_3, W_4 and W_5. and remove the paper and by joining the marked points show all forces in direction and magnitude. Refer to Exp. No. 1 and add these five forces as vectors, to form some sort of a polygon. The forces W_1, W_2, W_3, W_4 and W_5. may be taken in any order, but take care the arrow heads all follow round the figure from the starting point.

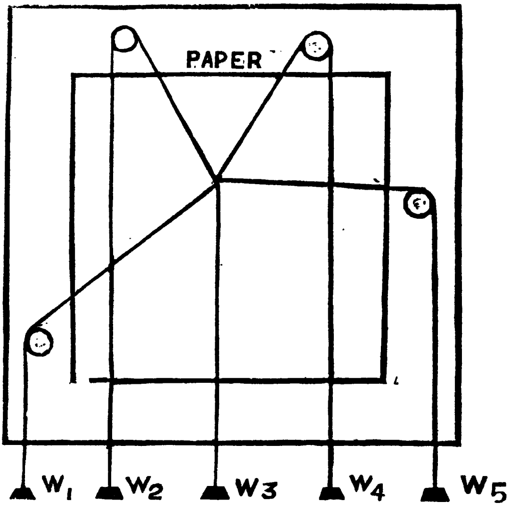


Fig. 2.

If the starting point be now joined through the finishing point we obtain the sum or resultant force; (or combined force) of these five. What does it amount to? (Allowance should be made for friction of pulleys.) Take the force W_1, W_2, W_3, W_4 and W_5. and change the order in adding them together again. What is now the resultant? Does equilibrium occur when we have a distinct resultant? Could you obtain equilibrium without this polygon becoming a closed (or nearly so) figure? If not, then why not?.

Alter all the forces and their directions and repeat the experiment. Is the result the same? Alter forces and again repeat the experiment. Is the result again as before? What does all this compel one to decide as to when a system of forces is in equilibrium? Write your conclusion with short account of experiment.

Ex.:—Four forces acting at a point are in equilibrium, the magnitude and direction of 3 of them are: 8 lb. acting due South, 15 lb. acting in a direction N. E., and 18 lb. acting in a direction 30° E of South. Find the mag. and direction of the fourth force.

EXPERIMENT No. 3.

Equilibrium of forces not passing through a point.

Apparatus. A force board, freely suspended, under the action of several forces. N. B. The board is not pinned at its centre.

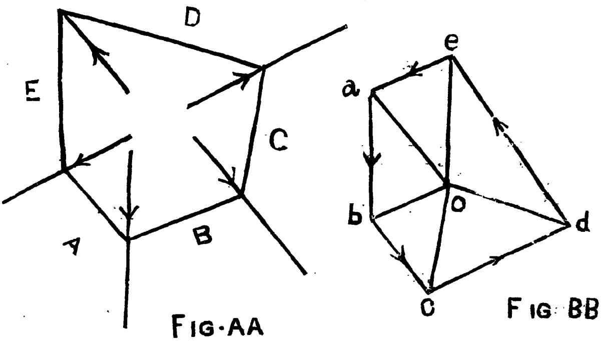
Method. For equilibrium two conditions must be satisfied.

(i) The forces balance (form a closed polygon if drawn to scale.)

(ii) Moments calculated about any point must balance.

Test if this is so, by drawing a force polygon, and by calculating moments, selecting any point, and including weight of board as force. The above conditions are satisfied when both the force polygon and the Funicular or Link polygon close. The Funicular polygon is much used in engineering design. You are to satisfy yourself by experiment that both force and link polygon close, when forces not passing through a point, are in equilibrium.

Having pinned a sheet of paper on to the suspended board, carefully draw lines of action of all forces (Fig. AA.) and note their magnitudes. Letter the spaces between lines of action, A, B, C, D, E, —— as shown, and now set out the force polygon (Fig BB.) lettering as shown.



FIG·AA

FIG BB

Fig. 3

Now select a point O as pole and join O to the points a, b, c, d, e, in the force polygon (Fig. BB). Now select a point on line of action of any force (say x on CO) and from x draw a link in space " D " (Fig. AA) parallel to line Od in Fig. 2. Continue drawing links in spaces A, B, C, E (Fig. AA) parallel to lines Oa, Ob, Oc, Oe, in Fig. BB. The last link in space C should close this link polygon (i. e., finish at x). If your link polygon does not close, or very nearly, check all your work. When it does so, alter arrangement of forces and repeat experiment. Repeat experiment again. Now write an account of experiment and your conclusions.

EXPERIMENT NO. 4.

Equilibrium of a body under the action of turning moments.

Object of the Experiment. Determine under what conditions a body, free to rotate only, will be in equilibrium under the action of turning moments.

Apparatus. A wooden disc pinned at its centre, with a frame, pulleys and weights, to apply forces.

Procedure. Adjust all pulleys to work freely. Now arrange say five forces (P. Q. R. S. T.) to act upon the disc as shown. The disc should come to rest in the same position (or nearly) when disturbed in either direction of rotation. Consider one force only, say P carefully place a set square along its line of action and measure the perpendicular distance from this line to the centre. Let p be this distance. The turning effect of the force P is, P multiplied by p and is equal to moment. This moment acts anti-clockwise. Enter the force P lbs, distance p and moment P X p lbs; in the table shown. Repeat this for each of the forces and complete the table, made in your book as shown below.

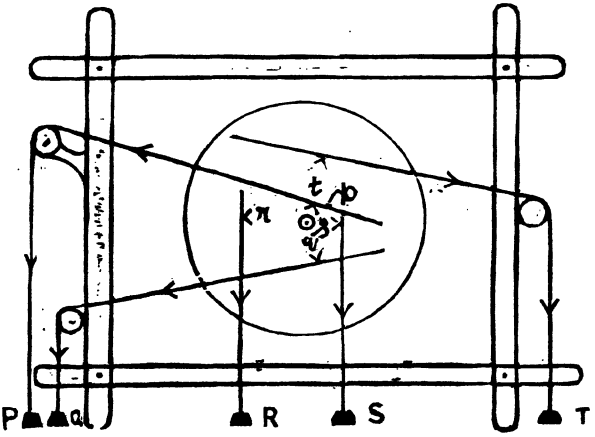


Fig. 4.

Clockwise moments.			Anticlockwise moments		
Force.	Perp. dist.	Moment.	Force.	Perp. distance.	Moments.
S lbs.	s	S×s lbs.	P lbs.	p	P×p lbs.
T lbs.	t	T×t lbs.	R lbs.	r	R×r lbs.
			Q lbs.	q	Q×q lbs.
Total clockwise moments.			Total Anticlockwise moments.		

What is the result? Allowance should be made for friction and inaccuracy. Change the forces in magnitude and point of application. and repeat the above, entering the results in another table. What is now the result? Alter the forces again and repeat the experiment. Is the result the same? What conclusion does this experiment lead to? Write down your conclusion.

Note. The unknown reaction at the centre pin, has no moment at the centre; it is therefore not taken into account.

EXPERIMENT NO. 5 A.

EFFICIENCY OF MACHINES—SCREW JACK.

Find the Velocity Ratio; Mechanical Advantage and Efficiency of Screw Jack.

Apparatus. A Screw Jack and weights.

Procedure. First find the distance the effort 'E' moves for one turn of the table. Do this by measuring the length of string unwound by one exact turn of the table. The load "W" on the table will move a distance equal to the pitch of the screw. Measure this also and calculate the velocity ratio,

$$\frac{\text{distance effort moves}}{\text{distance load moves}}.$$

Let 'V' equal Velocity Ratio. Now place 7 lbs. on the table and carefully find the effort which will just continue upward movement of table when given a start by hand. Now W is equal to load and E equals effort. Then ratio W/E is called the Mechanical Advantage. Increase the load W by 4 lbs. increments; in each case carefully find the effort "E" and enter results in table as below. As much load W as is available should be applied.

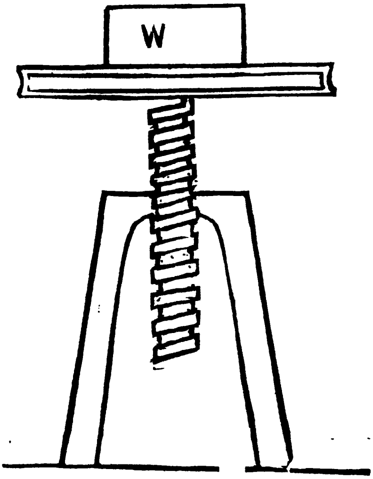


Fig. 5

Load W lbs.	Effort E lbs.	Mechanical advantage. W/E.	Load lost in friction. (EV − W)	Efficiency. W/EV × 100

Since if there was no friction, work given to machine equals work given out by machine; in one revolution we have W × (pitch) equals E × (distance effort moves) or W equals E × "V". The actual load W is less than this frictionless load *w* and the difference (*w*—W) or (EV—W) is the load lost through friction. Calculate this in column 4 of table. Also the efficiency is the actual load W divided by this frictionless load or efficiency equals W/E×V. Work out this in each case. Now plot graphs of "E" the effort; (EV-W) the load lost, and efficiency on W as base. Write your conclusions on this experiment.

Ex.:—A screw Jack has thread of 3/8" pitch and an efficiency of 37%. A load of 4 tons is to be lifted. Find the effort required if applied to a bar at a radius of 26" from centre of screw. What effort would be required if there were no friction.

EXPERIMENT NO. 5 B.

EFFICIENCY OF MACHINES—WORM AND WORM WHEEL.

Find Velocity ratio and efficiency of the worm and worm wheel.

The thrust of a screw is employed directly from its threads to drive the teeth of a wheel without the use of a nut. The threads of the screw or worm M have a cross section similar in shape to that of a spur wheel tooth and gear with the teeth of the worm wheel W. The worm is attached to a spindle S, at right angles to the axis of the wheel, and is prevented by its bearings from moving in the direction of its own axis, and the teeth of the wheel are inclined to the axis of the wheel at an angle *a* of the worm. When the worm is rotated by a pulley, a whole circumference of the worm thread between A and B comes during the rotation into contact with, say the right hand side of the tooth T on the worm wheel and so carries it forward by one pitch of the worm wheel since the worm is single threaded. Find the number of teeth in the worm wheel and hence determine the velocity ratio.

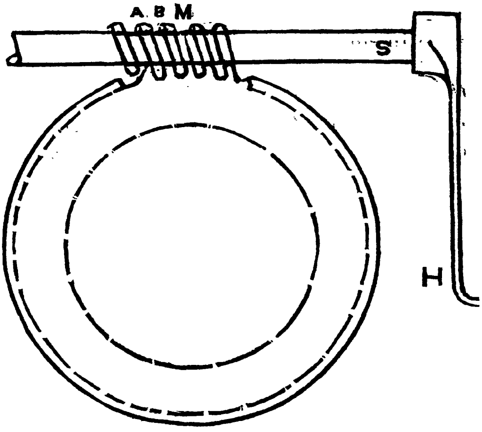


Fig. 6

Starting with a load W equals Q and increasing by regular increments, determine the effort required to lift the weight and tabulate the results as follows:—

Load W.	Effort P.	Mech Adv. W/P.	Load lost in Friction. PV—W.	Efficiency W/PV x 100.

Plot graphs of 'P' the effort; ($PV - W$) the load lost and efficiency on W as base. Write your conclusions on this experiment.

Ex : The worm shown in fig. is used as a lifting machine. The handle H is 15" long, the worm wheel W has 80 teeth, and the drum D is 6" dia. A rope ¾" dia. is coiled round the drum and carries a load of ½ T. What effort must be applied at the end of a handle to raise this load if the η *is 40 %?*

EXPERIMENT NO. 6.

PARALLEL FORCES.

Determine the reactions of a beam under various loading, and compare your results by direct reading of experimental model.

Procedure. First place a weight stirrup at some distance " a " from left end and note zero readings of balances. Now attach a load W_1 lbs to the stirrup. The parallel forces are now in equilibrium and therefore satisfy two conditions. What are they ? Take moments at " A " and calculate both reactions. Take moments at " B " and calculate reactions. Do your results agree ? Compare with balance readings after deducting zero readings. Enter results in table as below made in your book. Now add another load W_2 distance " b " from left end (Whenever stirrups are altered new readings should be taken of zero values). Again take moments at A and calculate reactions. Again take moments at B and calculate. Compare with balance readings, do all results agree or very nearly ?.

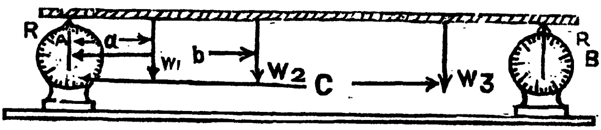


Fig. 7.

Add another weight W_3 distance " c " from left end. Again take moments at A and calculate reactions. Again take moments at B and calculate. Check these results by balance readings direct (deduct new zero values). Remove all loads and bring balances near together and take new zero value. Apply loads like W_1 and W_2 between balance and W_3 on projecting end. Take moments at both A and B calculating reactions each time. Check direct readings. If time permits rearrange the model so that both ends project beyond supports and repeat the experiment again. Enter results as shown below.

Reaction at A.		Reaction at B.
By moments at A equals	lbs.	By moments at A equals lbs.
do. B		,, B
By balance readings.		By balance readings.

Write down your conclusions on this experiment shortly, after completing your table.

Ex: A lever of wt. 9 lb. is 28" long. At one end is hung a wt. of 6 lb. and at the other end is hung a wt. of 20 lb. Find the position of the fulcrum so that the lever will rest in equilibrium in a horiz. position.

EXPERIMENT NO. 7.

Centre of Gravity of Plane Lamina.

Object of the experiment. Determine the centre of gravity of various figures cut in sheet metal, by experiment and by calculation.

Apparatus. Metal plates as above with means of suspension and a plumb line.

Procedure. The force of gravity acts upon every molecule of a body. The resultant of the parallel forces we call the weight and its point of application, we call its centre of gravity.

Take first the triangular plate. Suspend it by pricker at S passing through hole and passed into board behind, with plumb line in front as shown. It comes to rest so that its C. G. is vertically below suspension; (since in that position only is there no moment acting upon it.) Mark the point and remove the plate and join a to S. Select another hole for suspension and repeat above, obtaining another line on which the C. G. lies. The centre of gravity must be at the intersection of these lines. Check this geometrically, assuming the lines to be medians of triangle. Do your results agree? Now take the figure like M. N. O. P. and find its C. G. by experiment. Check the result as follows. Find by construction the C. G. of each triangle M. N. P. and N. O. P. and join them by a line. Find by construction the C. G. of triangles, P. M. O. and M. N. O. and join them by a line. The intersection of these two lines is the centre of gravity of the figure. Does it agree with the experiment? The remaining figures are important sections used in Engineering. Take first an I Section, second L Section and third ⊔ Section.

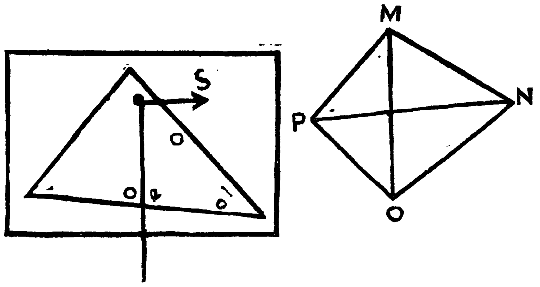


Fig. 8

In each case find the centre of gravity by experiment and also by taking dimensions and calculations of moments about two lines at right angles. Do your calculated and experimental book results agree? Show dimensioned sketches and calculations in your book and write an account of this experiment and also your conclusion.

Ex: The compression flange of a C. I. girder is 4" wide and 1½" deep; the tension flange 12" wide by 2" deep and the web 10"×1½". Find the distance of the centroid from the tension edge.

EXPERIMENT NO. 8.

Forces acting in members of a Roof Truss.

Object of the experiment. Determine the forces acting in each member of a loaded roof truss.

Apparatus. Model Roof Truss fitted with spring balances and weights.

Procedure. First see that the spring balances work freely, and take your readings of same. Now attach weight W as shown, and measure lengths of members AB, BC and AC. Draw this diag. (called structure diag.) to scale. Consider the forces at B. Three forces act at that point, the directions of all these being known, and the magnitude of one of them. Refer to Exp. No. 1. What do you know about the force diag. at such a point? Determine the forces in AB and BC, by drawing a Force diag., directions being transferred from Structure diag. on the same sheet of paper. Check the value of forces so found by balance readings. (Zero readings must be deducted).

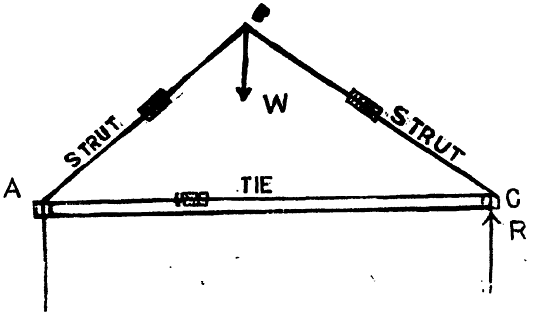


Fig. 9

Now consider the three forces acting at C. The reaction from the table "R" will be vertical. We have also found at once, the force in BC, and the force in AC, must now be found. Draw these three forces to scale, and so determine the force acting in AC. Check your value by balance reading. How does the stress in AC differ from that in AB and BC? Alter the weight "W" and also the lengths of AB and AC, and repeat the experiment. Make a table as shown below and enter your results.

Force in AB		Force in BC		Force in AC	
By Diag.	By Exp.	By Diag.	By Exp.	By Diag.	By Exp.

Ex:—In an iron roof truss one strut is 7 feet and the other is 9 feet and the tie is 14 ft. long. A load of 5 tons is being hung at the intersection of the struts. Determine the force acting in each member, and state whether tensile or compressive.

EXPERIMENT NO. 9.

Shear Legs.

Determine the forces acting in the members of a model of shear legs.

Apparatus. A model of shear legs fitted with spring balances as shown is provided.

Method. At the point P we have four forces in equilibrium, but not in one plane. We can however imagine the two legs PA and PB replaced by an imaginary one only at PC. We should then have at P forces in direction of W, PD and PC all being in one plane. First take zero readings of all balances. Next place a weight at P and measure lengths of PA and PB and also CD, DP and AB. Knowing PA, AB and PB draw this triangle to scale, and measure from it the length of the imaginary leg PC. Next set off PC, PD and W as shown. Draw a force diagram for point P setting W to scale, and finding forces in PD and PC, these three forces being in equilibrium. The force in PD is thus found, but the force in imaginary leg PC must now be resolved into two forces in actual legs, PA, and PB. Again set down force in PC and resolve in directions of PA and PB, transferring these directions from the first triangle drawn. Thus CO the force in leg AP is found, and OP the force in leg BP is also found. Now compare all the balance readings (Zero corrections being made) with the results obtained graphically. Do they agree? Now change the lengths of AB and PD and CD and repeat all the experiments. Do results agree with balance readings?

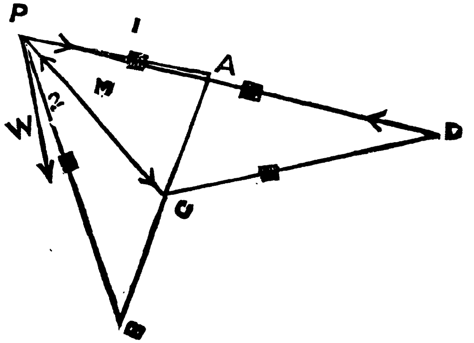


Fig. 10

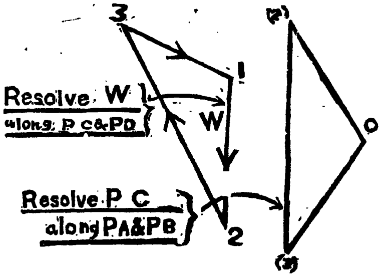


Fig. 11

Again alter lengths and repeat all the experiment again Write your conclusions on this experiment giving your reasons.

Ex.:—A pair of shear legs make an angle of 20° with each other and their plane makes an angle of 60° with the horiz. The back stay is at an angle of 30° to the horiz. Calculate the force in each leg and in the stay when supporting a load of 5 T.

EXPERIMENT NO. 10.

Periodic motion—Simple Pendulum.

Object of the experiment. Experiment on the periodic motion of a simple pendulum and find the value of 'g'.

Apparatus. Simple pendulum, a meter rule, and a watch for timing.

Procedure. Take a length 'l' of say 4 feet and find out whether the time of oscillation depends upon the amplitude 'a' or not. To do this count the number of oscillations per minute when started with 'a' equals 3″ and then 6″ and then 1′. Does the amplitude affect the time of oscillation? (Small differences may be neglected.) Now start with length l equals 1 foot and carefully count the number of complete oscillations in one minute (equals 'N'). Now 60/N is the time in seconds, of one complete oscillation. This is called the periodic time, T equals 60/N. Entering values of "l" and corresponding "N" in table as shown below, carefully find "N" for values of l equals 1 foot and 6″ then 2 feet and by increments of 6″ until l equals 6 feet has been tried. Complete the table by calculating T and T^2 in each case, and plot a graph of T^2 on "l" as base.

1 Foot	N	$T = \frac{60}{N}$	$T.^2$

Do your points lie on a straight line with reasonable errors? It ought to pass through the origin, and so satisfy the equation T^2 equals $c \times l$ where c is a constant. Find the value of 'c' from your graph. It can be shown that g equals $39{\cdot}5/c$. Calculate 'g' from this using the value of c you have found. Does this agree with what you would expect? Write your conclusions carefully.

Ex:—Using T^2 equals c. l., determine the lengths of pendulums which will give a complete single swing, and a complete double swing exactly in one second.

EXPERIMENT NO. 11.

Periodic Motion — Compound Pendulum.

Object. To find the value "g" by means of a compound pendulum and to determine the length of a Simple Equivalent Pendulum.

In the study of periodic motion we find that if T is the periodic time,

$$T \text{ equals } 2\pi\sqrt{\frac{\text{displacement}}{\text{acceleration.}}} = 2\pi\sqrt{\frac{\text{angular displacement}}{\text{angular acceleration.}}}$$

Here we have moment at O equal to W × d sin. θ.

Therefore W × d sin θ, is equal to $I_{oo} \times \frac{d^2\theta}{dt^2}$.

Now if θ is small sin. $\theta = \theta$.

Hence W × d × θ equals $I_{oo} \times \frac{d^2\theta}{dt^2}$.

$$\text{or } \theta / \frac{d^2\theta}{dt^2} = \frac{I_{oo}}{W \times d} = \frac{WK^2}{g \times w \times d}.$$

Hence T equals

$$2\pi\sqrt{\theta / \frac{d^2\theta}{dt^2}}.$$

$$= 2\pi\sqrt{\frac{K^2}{gd}}.$$

Where K is the radius of gyration about the axis through O.

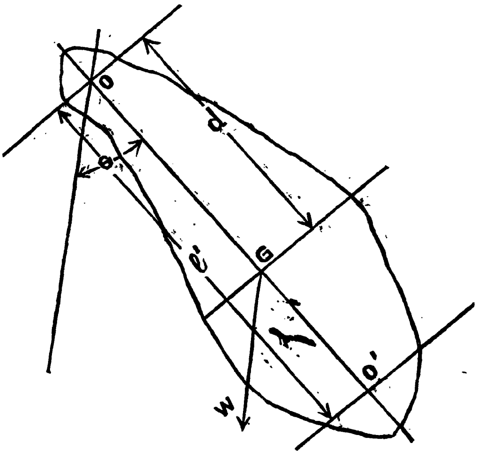


Fig. 12

In a uniform flat bar $I_{GG} = \frac{W}{g} \times \frac{l^2}{12}$

$$I_{oo} = I_{GG} + \frac{W}{g} \times d^2 = \frac{W}{g}\left(\frac{l^2}{12} + d^2\right) \text{ and } K^2 = \left(\frac{l^2}{12} + d^2\right)$$

Hence if the pendulum is a uniform bar we have T equals

$$2\pi\sqrt{\frac{\frac{l^2}{12} + d^2}{gd}}.$$

Take the flat bar and select some points of suspension at various distances "d" from its centre of gravity. Suspending from each point in turn, fill up the following table. With a simple pendulum $T = 2\pi\sqrt{\frac{l}{g}}$.

d	T	$\frac{T^2}{4\pi^2}$	$g = \frac{\frac{l^2}{12} + d^2}{d \times \frac{T^2}{4\pi^2}}$	l'

If l' is the length of a simple pendulum having the same period of vibration then $\frac{l'}{g} = \frac{\frac{l^2}{12} + d^2}{g\,d}$

or $l' = \frac{\frac{l^2}{12} + d^2}{d}$.

Calculate l' and fill in the column. Make a simple pendulum and take each value of l' in turn and by experiment find out if this is really the simple pendulum with the same period of vibration. The point 0′ distance l' from 0 is called the centre of oscillation. If 0′ be taken as point of suspension instead of 0, the periodic time will remain unaltered.

Test this in the various cases.

Ex: Calculate the period of oscillation of a solid steel ball 1" dia. rolling inside a fixed rough concave spherical surface having a radius of curvature of 6".

EXPERIMENT NO. 12 A.

Laws of Friction between solid bodies.

Object of Experiment. Investigate the laws of friction between solid bodies.

Apparatus. A wooden sliding board with pulley and sliders of various materials.

Procedure. First use a slider with wood base and weight it, and also weigh~~t~~ the scale pan P. Apply further small weights to scale pan until the slider is just kept moving, after being started by a slight push behind. It will thus be seen that static (at rest) friction, is greater than sliding friction. (It may be found that one part of the board has more friction than the another. If so select a short length say a foot for all tests.)

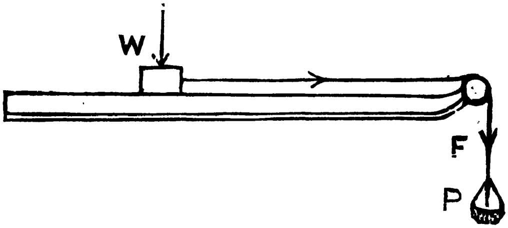


Fig. 13

Now place a 1 lb. weight in the slider and carefully adjust weight in scale pan to just maintain a slow motion. Entering values in table as shown, continue the test until about 20 lb has been reached by additions of 1 lb in slider. Plot the values of F and W and try if a straight line lies fairly on the points. Determine its equation in the form $F=a+bw$. What pull would be required to draw a load of 1 ton? How much would a pull of 1 cwt keep in motion? Obtain sliders and bases of different materials and repeat all the above experiments and calculations. Does frictions depend upon materials used or not? Try a 10 lb. load with as many different materials as possible. Next obtain sliders of the same materials but of different areas of base. Find by trial whether friction depends upon area of surfaces in contact. What is your result? You have discovered four laws of solid friction, what are they?

Write a short account of the experiment, on what you have found out about friction, and your conclusions. All observed values must be entered in table as shown and graph plotted standing materials used.

Total Normal Pressure	Frictional Resistance.	Coefficient of friction.
Including Slider = W	Including Scale Pan = F	$\mu = \frac{F}{W}$

Ex:—A metal planing machine, the table of which weights 2 cwts., makes 7 backward, and 7 forward strokes.in a min. If the length of each is 3' and μ *betueen the sliding surfaces is 0·06, how many ft. lb. of work are done per min, on moving the table?*

EXPERIMENT NO. 12 B.

Laws of Friction between solid bodies.

Object of Experiment Investigate the laws of friction between solid bodies.

Apparatus. A sliding board as inclined plane, sliders and weights. First consider the forces acting when a body rests upon an inclined plane. The weight W may be resolved into components 'R' the reaction of the plane (perpendicular to its surface) and the components 'P' along the plane. The normal reaction 'R' brings into action a frictional resistance f. So long as f exceeds P motion cannot be self maintained, when by increasing the inclination of the plane we get motion steadily maintained, then P must just equal f. If θ is then the inclination, P equals W sin. θ. Also R equals W cos. θ Now dividing the pull required P (equals W sin. θ) by the normal reaction R (equals W cos. θ), we obtain coefficient of Friction μ $\left(\text{equals } \frac{\text{W sin. } \theta}{\text{W cos. } \theta}\right) = \text{Tan. } \theta$.

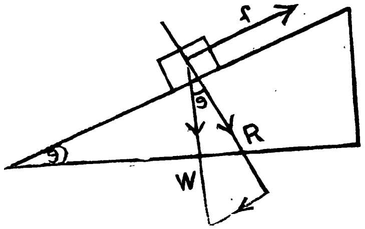


Fig. 14.

Now take a slider. Carefully find out the least inclination θ which will maintain motion after starting. Note the value of θ, add 2 lbs, then 4 lbs, then 6 lbs, and finally 8 lbs, to the slider. In each case carefully determine the least angle θ. Enter all results in a table showing load in slider, angle θ and coefficient of Friction μ equals tan θ.

Select sliders and bases of different materials and repeat all the above experiments. The average value of tan θ may be regarded as the most correct value of μ. for each material.

Try the slider with reduced areas of contact. Does it affect the friction, or is friction independent of area of contact?

Write down your conclusions.

Ex :—A rider weighing 8lbs. rests on a plane at 15° to the horizontal. A pull down the plane of 1lb. is required to maintain motion. What is the Coefficient of friction between the surfaces?

EXPERIMENT NO. 14.

Properties of materials.—Stress Strain Diagrams.

Experiment and draw stress—strain diagrams for the various samples of wire provided.

Apparatus. A length of soft iron, copper, or brass wire, vernier, and weights.

Procedure. First by means of a micrometer determine the exact diameter of the wire and calculate its sectional area. Remove any bends or twists in the wire and adjust the vernier to zero reading. Now measure the length of test wire from the upper attachment to the point of attachment of vernier, carefully place a load of 1 lb on the wire and read off the vernier. By subtraction obtain the extension and enter in table as shown. Add another one lb, and observe new values; and continue loading by 1 lb. increments and reading off the vernier until the wire breaks. The wire may stretch until the sliding scale of the vernier comes out below remainder; when this occurs an ordinary rule will be sufficiently accurate to measure extension. Dividing each load by the sectional area of the wire we obtain the stress. Dividing extension by original length of wire we obtain the strain. Do this throughout, entering values in table as shown. Also plot the stress strain curve with the strain along the X axis and the stress along the Y axis.

Load.	Extension.	Stress $\frac{\text{Load}}{\text{Area.}}$	Strain $\frac{\text{Extension}}{\text{Original length.}}$

Repeat this experiment for as many different materials as possible. Write your conclusions, on the experiment. Mark the point on the graph which you consider is the yield point. Calculate 'E'. Does Hooks law appear to apply to each case? What do you call the extension before the yield point is reached and what after that point?

EXPERIMENT NO. 15.

Properties of materials—Determination of Modulus of Elasticity.

Object of experiment. Experiment on the elasticity of the wire provided, and determine its *Modulus of Elasticity.*

Apparatus. A test wire with hook and weights and vernier.

Procedure. First determine the length of the wire from clamp above, to attachment of sliding scale of vernier. The latter point may be adjusted to give an exact number of inches. Now observe vernier reading carefully and note it swing to and fro. Read again the vernier and by subtraction find its extension. Enter results in tabular form. Do not handle test wire at all or inaccurate values will result. Continue adding loads of 1 lb. each time finding the extension, until a maximum load of 20 lbs. is reached, entering all values in table. Now reduce the load by 1 lb. at a time again reading and making note of extension in table. Take off all the loads you put on. Is the final vernier reading the same as when you started? What do we call this property by which the wire returns to its original length? Plot all your observed values (Load vertically) and try if a straight line can be drawn fairly among the points. Using a micrometer find the diameter of the wire, and its sectional area. Calculate the stress when 20 lbs. is applied and also the strain. Dividing stress by strain, find the Modulus of Elasticity E of the wire. The graph you have drawn is also a stress-strain

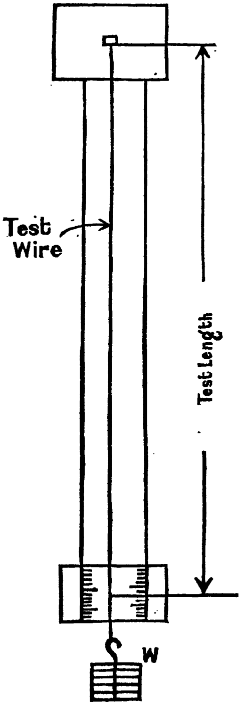


Fig 16.

graph to another scale. What simple law connects these quantities? By what name is it generally known? Suppose the wire could go on stretching uniformly what would be its length when a stress equal to E lbs. per square inch is applied?

Write your conclusions on this experiment.

Ex:—What load must be applied to a wire 1/8" diameter to stretch or extend it to 1/100" if the wire is 60 feet long and $E—28 \times 10^6$ *lbs, per square inch.*

EXPERIMENT NO. 16.

Deflection of Beams.

Apparatus. A model lathe bed with arrangements for fixing or for suspending beams, a vernier to measure deflections. First take a steel beam of rectangular section and secure it firmly at one end in clamps, the other being free as in cantilever. By loading at 3 feet from fixing obtain a deflection of about 2″. Now find the deflection at 2 feet and 1½ feet from the fixed end with same load. Is the deflection proportional to the length cubed? Test this again using another beam of small section and supported at both ends, taking spans of 3 feet, 2 feet and 1½ feet. Make two graphs of deflection $\Delta \propto l^3$. and l^3 and satisfy yourself that $\Delta \propto l^3$.

Next by using the same beam in each of above settings, satisfy yourself that Δ depends on method of securing beam. With say $l^3 = 8,3$ and the same load W lbs. you should get ratio of deflections as 8 : 3. Is this so? Now calculate the moment of Inertia I for these different beams of the same material. I equals $\frac{bd^3}{12}$ for rectangle; I equals $\frac{s^4}{12}$ for square; and I equals $\frac{\pi d^4}{64}$ for circular section. Taking a constant span equals 3 feet and a constant load at centre, obtain deflection for each beam. The quantity $\Delta \times I$ for each beam should be approximately constant. or $\Delta \propto \frac{1}{I}$ Does your results agree with theory?

By testing under the same conditions beams of different materials satisfy yourself that the deflection depends upon material used. Collecting results we have $\Delta \propto \frac{Wl^3}{EI}$ and also on method of securing beam and on materials.

The complete expression is $\Delta = \frac{Wl^3}{K \times EI}$ and K equals 48 for beam supported at both ends and loaded in middle.

Using values already found calculate E for steel by substituting result of experiment in this expression.

Write an account of this experiment and your conclusions.

Ex.:—A beam of I-Section, 14" deep, is simply supported at the ends of a 20 ft. span. If the M. I. of the area of cross-section is 440 in.^{4}, *what load may be hung midway between the supports without producing a deflection of more than ¼". E = 13,000 T / □".*

EXPERIMENT NO. 17.

Laws governing the strength of beams.

Apparatus. A lathe bed, wood beams of various sections, and weights.

Part I.

Procedure. Select two beams of one square inch section of the same kind of wood. Adjust the span to 36″ so has to have a standard Test Beam (One square inch section, 36″ long and loaded in middle). Commence loading with 4lbs. increments, reading off deflection on vernier in each case. Continue this until the beam breaks. Plot the deflection on load as base. Now take the second beam similar to above and adjust the span to 24″ and load in middle as before. Make the experiment exactly as above, and again reading deflections until beam breaks, plotting the new graph. What is the approximate ratio of these breaking loads? We assume breaking load is inversely proportional to length of beam. Do you agree this is so?

Take two beams similar to above, of another kind of wood. Repeat above experiments. Are the breaking loads approximately in the ratio of 2 is to 3? Does the kind of wood affect the strength? Would you expect this? Write an account of this experiment and your conclusions.

Part II.

Select two beams of similar wood to either of above, in this case one being $1'' \times \frac{3}{4}''$ section and the other $1'' \times \frac{1}{2}''$ section. With span of 36″ and depth 1″ in each case, gradually load in centre and note deflections until the beam breaks. You have now tested three beams with constant length and depth but varying width. How does the breaking load depend upon the breadth? Finally take two other beams as above, but now take length 36″ and breadth 1″ in each case, the depth varying, and load gradually in centre as before. You have now tested three beams with constant length and breadth. How does the breaking load depend upon the depth? We usually say $W \propto d^2$. Do you agree? Collecting all the results we have W equals $CK\frac{bd^2}{l}$ where C is a constant depending on kind of wood, K is a constant depending on method of loading b equals breadth, d equals depth, and l equals length. Do you agree with formula? Write your conclusions.

Ex.:—A beam of the wood you have tested is 16 feet between supports and 12″ deep and 9″ wide. If loaded in centre what is safe load if factor of safety is 4. (In this case K equals 1).

EXPERIMENT NO. 18.

Belt and Coil Friction.

Investigate the connection between the friction of a belt on a pulley and the angle of lapping of the belt.

Apparatus:— You are provided with a pulley and a leather belt and arrangements for adjusting the angle of lap of the belt. First adjust the angle of lapping ϕ to 90° as shown. With 4 lbs. equals T_2 hanging on the belt, determine the pull T_1 required to maintain a steady motion, as in other friction experiments. Now increase ϕ to 105° and find the new value of T_1. Continue increasing ϕ by 15° increments up to ϕ equals 270° in each case finding T_1 and entering in table:—

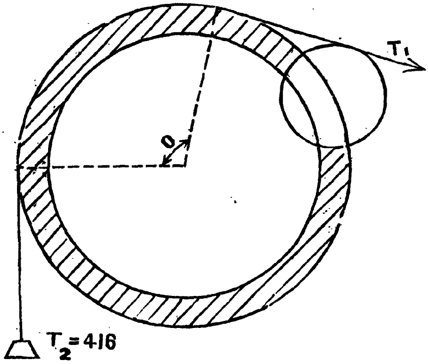


Fig. 17.

ϕ	90°	105°	120°	135°	150°	165°	180°	195°	210°	225°
$\frac{T_1}{T_2} = 4$										
$\text{Log}_{10} \frac{T_1}{T_2}$										

Now divide each value of T_1 by T_2 equals 4. Also tabulate $\text{Log}_{10} \frac{(T_1)}{T_2}$ as shown. Plot ϕ and $\text{Log}_{10} \frac{T_1}{T_2}$ as base. We are led to expect a straight line graph. Do your values agree approximately? We may write for this result $\text{Log}_{10} \frac{T_1}{T_2}$ equals $K\phi$. What is the value of K?

Again $\text{Log}_e \frac{T_1}{T_2}$ equals $2{\cdot}303\,K\,\phi$ equals $2{\cdot}303\,K \times 57{\cdot}3\,\theta$ if θ is in radians. Hence $\frac{T_1}{T_1}$ equals $e^{57{\cdot}3 \times 2{\cdot}303\,K\,\theta} \doteq e^{132\,K\,\theta}$.

This ratio $\frac{T_1}{T_2}$ must depend upon the co-efficient of friction. Here we have $\mu = 132$ K. What is the value of μ? Is it what you would expect? Substituting, we get $\frac{T_1}{T_2} = e^{\mu\theta}$ as the relation we have established; θ being in radians.

Repeat all the experiments with T_2 equals 2 lbs.

Write your conclusions as to the law of friction and angle θ.

Ex.:— A load of 360 lbs. is to be held by a belt passing round a pulley. If μ equals 0'28 and a force of 10 lbs. only is applied at the other end of the belt, what angle of lapping is necessary?

EXPERIMENT NO. 19.

Simple Train of Wheels.

Toothed or Spur wheel gearing is capable of transmitting a considerable amount of force, and is a very important means of transmission of motion and power. It is convenient to think of the teeth and the spaces as being formed above and below the curved surfaces of the wheels or cylinder which when working together on two parallel shafts, would give the same velocity ratio as is required of the actual toothed wheels. Such cylindrical surfaces are called the *pitch surface*, and are shown in the figure by the dotted pitch circles. Pitch circles are, then, circles centered at the spur-wheel centres, and having the same radii as those of corresponding friction wheels to give the same velocity ratio. If a wheel has say, 15 teeth, and 15 spaces between them, a tooth and adjoining space must together occupy 1/15 of the circumference of the pitch circles. This amount is called the *circular pitch* of the teeth, that is, the distance measured along the circumference of the pitch circle from a point on one tooth across the intervening space to the corresponding point on the next tooth, or the length on the circumference of the pitch circle occupied by one tooth and one space as shown at $x\ y$.

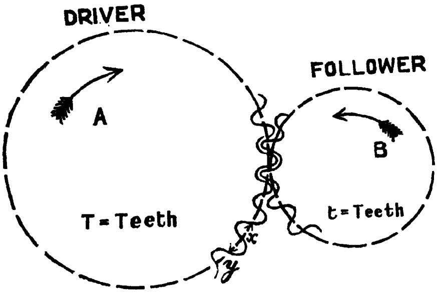


Fig. 18.

If a wheel of diameter d ins. has n teeth, circular pitch in ins. (equals p) equals circumference of pitch circle/n equals $\pi\ d/n$. Or No. of teeth n equals $\pi\ d/p$.

The number of teeth and spaces must evidently be a whole number, so that the pitch p must divide exactly into the circumference $\pi\ d$, giving a whole number n. Hence we have the following relations :—

n equals $\pi\ d/p$, p equals $\pi\ d/n$, d equals pn/π.

The velocity ratio of a wheel A driving a wheel B may be found as for the friction wheels, which might replace the pitch surfaces—

$$\frac{\text{Revolution per minute of follower B}}{\text{Revolution per minute of driver A}} \text{ is equal to}$$

$$\frac{\text{Diameter of pitch circle of driver A}}{\text{Diameter of pitch dircle of follower B}}.$$

But since the diameters of the pitch circles are proportional to the circumferences, and the wheels A and B, to work together, must have the same pitch, the circumferences are proportional to the number of teeth in the wheels:—

$$\frac{\text{Revolutions per minute of follower B}}{\text{Revolutions per minute of driver A}} \text{ is equal to}$$

Number of teeth in driver A / No. of teeth in follower B. A large velocity ratio cannot be obtained by the use of 2 spur wheels without one of them being inconveniently large. In such cases a train of wheels is used as shown in the figure, the motion being transmitted from the driver A on shaft 1, through wheels B and C keyed on shaft 2, then through wheels D and E keyed on shaft 3 to the follower F keyed on shaft 4. The wheels B and C, or the wheels D and E instead of being keyed separately on to the shaft 2 or 3, may be all in one casting in which case it is called a compound wheel. Let A, B, C, D, E, F represent the number of teeth in each wheel, if shaft 1 makes one revolution,

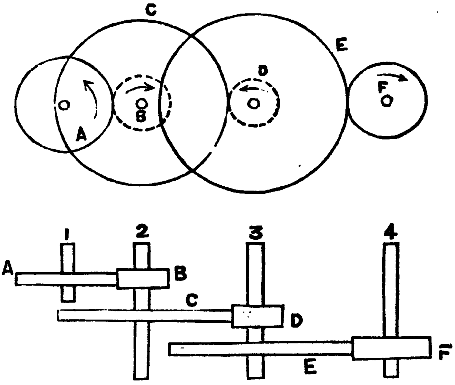


Fig. 19.

Revolution of shaft 2 equals Revoln. of shaft 1 $\times$ A/B = A/B.

Revolution of shaft 3 equals Revoln. of shaft 2 $\times$ C/D = A/B $\times$ C.

Revolution of shaft 4 equals Revoln. of shaft 3 $\times$ E/F = A/B$\times$C/D$\times$E/F.

Hence the revolutions or the velocity ratio of last shaft per revolution of the first shaft, or $\frac{\text{Revolutions of last shaft}}{\text{Revolutions of first shaft}}$ equals A/B$\times$C/D $\times$ E/F

$$\text{equals } \frac{\text{Product of numbers of teeth in drivers}}{\text{Product of numbers of teeth in followers}}.$$

Study the given apparatus and determine exatly its velocity ratio. Starting with a load W equal to zero and increasing by regular increments, determine the effort required to lift the weight and tabulate the results thus:—

Serial No.	Load W	Effort P	Vel. ratio V	Mech. adv W|P	Friction (PV−W)	Efficiency % W/PV × 100

Change one set of gear wheels and repeat the expt. with another velocity ratio.

Plot graphs of P the effort; (PV − W) the load lost, and efficiency on W as base.

Ex:—In the train of wheels shown in Fig. A has 20 teeth, B has 30 teeth, C 120 teeth, E 95 teeth, F 25 teeth. A makes 30 and F 456 R. P. M. How many teeth must the wheel D have?

EXPERIMENT NO. 20.

Extension of Springs.

Object: To determine:— (a) The time of vibration of a weight when caused to oscillate on a helical spring of known stiffness; (b) to verify the formula

$$T = 2\pi\sqrt{\frac{\text{displacement}}{\text{acceleration}}}.$$

Apparatus:—A helical spring, hanger, weights, stop watch and a yard stick.

Procedure:—Suspend the spring from a firm support, place the hanger on its lower end, and proceed to find the stiffness (S), i. e. the load required to stretch the spring 1 foot. If the spring is tightly wound place a sufficient weight on the hanger to open the coils, then measure the height (H) of the upper edge of the weight from the floor (see fig.), now place a known weight (W lb.) on the hanger and after it has come to rest again, measure the height (now h) of the upper edge of the first weight from the floor, then the extension of the spring, equals $(H-h)$ ins. or $(H-h)/12$ ft. Therefore S equals $= W \div \frac{(H-h)}{12} = 12\ W/(H-h)$. Repeat this experiment, using three different weights, and take the mean as the required stiffness.

Having determined the stiffness of the spring place on the hanger a weight such that the weight on the hanger, and the added weight together make up a weight of ——— lbs. Now displace the load through 1 in. from a position of rest, then release it, and note the no. of complete oscillations (N) in t seconds; the time of one complete oscillation t equals t/N. Repeat the experiment, making the displacement x equals 2 ins. after which repeat the work with loads of ——— lbs, ——— lbs, and ——— lbs.

It may be shown that for a motion of this kind the periodic time

$$T = 2\pi\sqrt{\frac{\text{Displacement}}{\text{Acceleration}}} \dots (1)$$

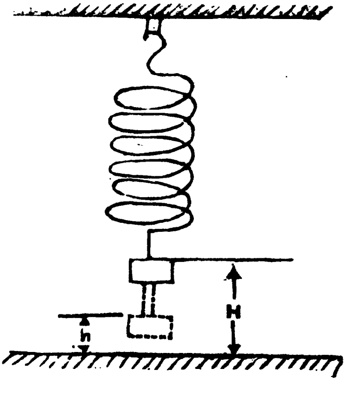


Fig. 20.

The pull or push, exerted by the spring on the weight W for a given displacement x equals S x and

$S x : W :: a : g.$ or $a = S. x g / W$, where a is the linear acceleration produced on the weight W. Substituting in equation (1) we get

$$T = 2\pi\sqrt{x \div \frac{Sxg}{W}} = 2\pi\sqrt{\frac{W}{Sg}}.$$

Tabulate all observed and calculated quantities as shown in the given table.

Plot the graph of T^2 (vertically) against W and infer from your graph what fraction of the weight of the spring should be added to W in the general formula given above. Is the periodic time independent of the amplitude ?.

Results of the Experiment.

Stiffness of Spring S equals lbs per foot.

Observed.				Calculated.	
I	II	III	IV	V	VI
No.	Load W in lbs.	Displacement x	No of Oscillations in t sec. equals N.	Periodic Time T $= \frac{t}{N}$	Periodic Time T $= 2\pi\sqrt{\frac{W}{Sg}}$

Ex :— A light helical spring is found to stretch 0·4" when an axial load of 4 lb. is hung on it. How many vibrations per min. will this spring make when carrying a wt. of 15 lb.

* * *

EXPERIMENT NO. 21.

Torsion of Wires.

Apparatus. A length of steel wire is provided secured at one end, with a pulley and bearing for applying torsion at the other. A spring is also provided (made of the same material.)

Procedure. We calculate the extension of a spring, on the theory that is due to torsion produced in the material. Find out if it is correct.

First calculate the length of the wire (actually coiled) in the spring and also its dia. Satisfy yourself that the length of the wire above (from fixing bearing to pulley) and its dia. is the same as the spring, and also that the pulley has the same radius as the spring. Remove the spring and experiment on the wire alone. Apply loads up to 12 lbs. by 1 lb. increments, and measure the fall of the pointer due to twisting of wire. Fill in the values in table as below.

Now experiment on spring alone using a small bracket for suspension. Again apply loads up to 12 lbs. by 1 lb. increments and read off all extensions and again enter in table

Finally arrange wire and spring to act together and apply loads as before, reading off extensions (total) and enter in table.

Load = W	Fall of Pointer	Radians θ	Extension of spring x	Extension Combined Spring & Wire
1 lb. 2 lbs. etc.				

Now compare your figures and state your conclusions. Is the theory stated above correct? Now fill in values of θ Radians by dividing the fall of pointer by radius of pulley. Take W = 12 and corresponding value of θ and substituting, calculate the modulus of Rigidity "N" from $\theta = \frac{32\,T\,l}{\pi\,N\,d^4}$ where T = Twisting moment, l = length and d = dia. of the wire. Use this value of N and calculate $x = \frac{64\,W\,R^3\,n}{N\,d^4}$. R = radius of coil of spring, n = number of coils. Does this agree with observed value?

Ex:—A spring has 10 coils of ¼" dia. wire with 3½" dia. coils. If N = 13 × 10⁶ lb./□", Calculate extension 'x' and angular twist θ when 56 lb. is applied.

* * *

EXPERIMENT NO. 22.

Determination of Moments of Inertia. (Torsion.)

If a body is hung by a filament (thread, string, wire etc.,) its movements are more or less affected by the elasticity of the suspension, for whenever a filament is twisted forces come into play that tend to make it untwist. These are called *torsional forces,* and the body is said to be affected by a *torsional stress.* Their magnitudes are greater when the angle through which the filament is twisted is larger.

A suspended body when affected only by forces e. g. weight parallel to the axis of suspension rests in an equilibrium position in which the filament is not twisted. Let the body be turned from this position, the suspension is more or less twisted and torsional forces come into play: these oppose the turning movement of the body. If the body is turning freely, then as the regular space traversed increases, the opposing torsional forces increase and presently stop the movement of the body. The next moment the body, in obedience to the torsional forces, begins to return towards the equilibrium position. The continued action of the torsional forces makes the body gain velocity from moment to moment and therefore it does not stop at, but passes through the equilibrium position; the suspension now becomes twisted in the reverse way, and torsional forces again oppose the angular movement, presently stop it, and then bring the body back towards the equilibrium position. Again velocity and momentum are acquired, the body passes through the equilibrium position and swings over to the first side. The movements are then repeated and so on. Thus the body oscilliates about its equilibrium position; it forms a *torsion pendulum.*

It can be shown that t equals $2\pi\sqrt{\frac{I}{c}}$ where t is the period of oscillation, I the M. I. of the body about the axis of vibration,

and c the moment of the torsional couple called into operation by a unit twist (one radian).

The form of this expression is the same as for the common pendulum. The torsional oscillations are isochronous whatever be the angle (within wide limits) of vibrations. It therefore follows that the force of torsion is proportional to the angle of twist. When there is equilibrium the moment of the torsion couple equals that of the applied couple that produces the twist. Therefore the angle of twist is proportional to the moment of the *applied couple.*

To determine the moment of inertia of the torsion disc (which is prepared as an oscillator.)

Apparatus. Torsion disc, 4 small rods, Tripod stand, Brass discs, and cylinders of known weight, stop watch.

The apparatus for the determination of the M. I. of the disc consists of the disc suspended horizontally by a wire, and clamped at the top of the stand. The disc is allowed to vibrate and the interval of a dozen swings is then determined.

The cylinders of known dimensions are then placed on the small rods fixed at definite distances from the axis of suspension. The disc is once again allowed to vibrate and the interval of a dozen swings determined. Tabulate the results thus.

Weight of cylinder.
Weight of disc
Value of weight.

Experiment.	1	2	3	4	5	6
	Disc alone.	Disc plus 2 cylinders.	Disc plus 2 cylinders plus 4 weights.			
Dist. between wire and centre of Gravity.						
Period in Seconds.	$=x$					
Sq. of period.	$=x^2$					
$\frac{\text{Period}^2}{x^2}$	$=1$					
M. I. of the system.	$=I$	$I+I_2$	$I+I_3$			
$\therefore \frac{\text{M. I.}}{\text{I.}}$	$=\frac{I}{I}=1$	$\frac{I+I_2}{I}$	$\frac{I+I_3}{I}$			
		$\frac{I_2}{I} = a$ (say)				
		$\therefore I = \frac{I_2}{a}$	(As I_3 and a are known, I can be determined.)			

Check the values of I obtained from the other cases with this rule. Also calculate approximately the value of I.

Note. The M. 1. I of the disc is constant throughout, and is not necessarily related in a simple manner to the moments of inertia with the cylinders added. Hence if I is subtracted from each of the latter, the respective remainders are the moments of inertia of the cylinders in their several positions, and should roughly vary as (Mass of cylinders) × *(mean distance from axis of rotation)*^{2}.

The subtraction of I is effected by assuming the moments of inertia to vary as the squares of the respective periods. Hence express the ratio to I of the total moment of inertia in each case, then deduce the value of the moment of inertia of the disc.

Ex. :—A vertical shaft, 8 ft. in length, is fixed at one end and has a diameter of 4 in. for a length of 5 ft. from that end and a diameter of 3 in. for the remainder of its length. If a disc of M. I 3,200 lb. ft.^{2} *units is attached at the free end of the rod, determine the frequency of the natural torsional oscillations of the system.* $N = 12 \times 10^6$ *lb/□".*

EXPERIMENT NO. 23.

Percentage of voids in jelly and sand.

Concrete. This consists of aggregate and matrix. The latter binds the former. The strongest and hardest ingredient is the aggregate; so that the concrete will be strongest which contains the maximum aggregate. But the difficulty comes in cementing these aggregate particles together. So enough matrix has to be added so that the voids or interstices in the aggregate may be well filled up. In order to determine the quantity of matrix to be added, the proportion of voids in the jelly or sand should be first determined. The cement or lime used must be sufficient to fill up the voids in the sand. The mortar so prepared must be sufficient to fill up the voids in the aggregate.

Procedure :—Weigh the bucket empty. Fill it up with dry jelly and weigh again. Add water till no more water will sink down and the bucket is just full. Care must be taken not to add too much water. Weigh again. Calculate the quantity of water used. Measure the top and bottom diameter of the bucket and height. Calculate the % of voids by volume and by weight. Find the density of the stone from which the jelly is made. Assume 1 cft. of water equals 62·4 lbs.

Repeat the above experiment using sand. Take particular care that no more water is added than will be just absorbed by the sand. Excess water will vitiate the results.

Observation and Record :—

Capacity of bucket equals
Weight of bucket equals
Weight of bucket plus substance equals
Wt. of bucket plus substance plus water equals
Weight of substance equals
Weight of water ,,
% of voids by weight ,,
Volume of bucket ,,
Volume of water added ,,
% of voids by volume ,,
Density of material ,,

Ex :—Find the relative quantities of dry materials to be used of coarse aggregate having 48 % voids and fine aggregate or sand having 30 % voids, the mortar to be 1 of cement to 2 of sand and 25 % in excess of the voids of the large aggregate.

EXPERIMENT NO. 24.

Fineness and Setting time test of Cement.

Fineness Test.

General:—According to the B. S. S. (latest) the Cement shall comply with the following conditions of fineness. 100 grams of Cement shall be continuously sifted for a period of 15 minutes on a seive of B. S. No. 170 and the residue for a period of not less than 5 minutes on a seive of B. S. No. 72 with the following result.

(1) The residue by weight on a sieve of B. S. No. 170 must not exceed 10 %.

(2) The residue by weight on a sieve of B. S. No. 72 shall not exceed 1 %.

Sieving surface shall be not less than 50 sq".

The sieves shall be prepared from standard wire and the diameter of the wire from the 170 mesh shall not be less than 0·00171" nor more than 0·00189" and for the 72 × 72 mesh, the diameter shall be 0·0044". The wire cloth shall be woven and not twilled, the cloth being mounted on the frame without distortion.

Procedure:—Take 100 grams of the cement supplied, and sieve it for 15 minutes in 170 × 170 sieve. Weigh the residue.

Sieve the residue in 72 × 72 mesh for 5 minutes. Weigh the residue. Note the % Repeat the experiment for the various samples supplied and note them.

SETTING TIME TEST.

General:—According to the B. S. S. Cement shall be classified in two gradations. (a) *Normal setting Cement*: Initial setting time shall not be less than 30 minutes, and final setting time shall not be greater than 10 hours.

(b) *Quick Setting Cement*: This must have an initial setting time of not less than 5 minutes, and final setting time of not more than

30 minutes. The term quick setting does not necessarily imply that the cement hardens quickly.

Procedure :—1 lb. of cement shall be mixed with such a proportion of water that the mixture shall be plastic when filled into the vertical mould. The gauging shall be complete before any sign of setting occurs. Ordinarly 100 cc of water will be required for 1 lb. of cement. Too little water will show a lower setting time and too much water will show a higher setting time. So it is important that only just the required quantity and no more water is added.

The initial and final setting time of cement gauged as above, shall be determined by the Vicat needle apparatus which consists of a frame D bearing a movable rod B with the cap A at one end. The removable needle shall be one *mm* ('039″) square in section with a flat end. The rod B carries an indicator which moves over a graduated scale attached to the frame D. The cap rod and needle with all attachments shall together weigh 30 grams. The mould for the Cement consists of a split ring E (80 *mm.*) in diameter 40 *mm* high, which rests on a nonporous plate.

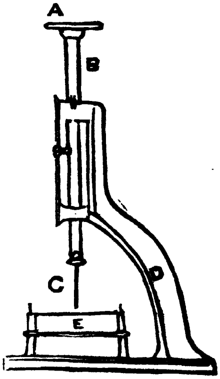


Fig 21.

Determination of the initial setting time :—

For the determination of the initial setting time the test block confined in the mould and resting on the plate shall be placed under the rod bearing the needle; the latter shall then be lowered gently into contact with the surface of the test block ,and quickly released and allowed to sink into the same. Care must be taken to see that the needle rests with its full weight upon the surface of the test block. This process shall be repeated until the needle, when brought into contact with the test block, and released as above described shall not pierce it completely. The period elapsing between the time when the cement is filled into the mould and the time at which the needle ceases to pierce the test block completely shall be the initial setting time referred to above.

Determination of final setting time :—

For the determination of the final setting time the needle C of the Vicat apparatus shall be replaced by the needle F. The cement shall be considered as finally set when upon applying the needle gently to the surface of the test block, the needle makes an impression thereon, while the attachment shown in the figure fails to do so. In the event of a scum forming on the surface of the test block, the underside of the test block may be used for determing the final test.

Observation and Record :—

Residue on 170×170 mesh sieve (15 min) %
„ „ 72×72 „ „ (5 min) %
Initial setting time ....
Final setting time ....

EXPERIMENT NO. 25.

Preparation of Neat Cement Briquettes with different Percentages of Water.

General :— British standard specifications state that neat cement briquettes prepared and gauged in a particular manner shall have a breaking strength of not less than 600 ℔s/□″ tensile after 7 days. In the latest specifications the strength after 28 days has been omitted.

Gauging of cement :—Cement shall be mixed with such a proportion of water that after filling the mould the mixture shall be plastic. Clean appliances should be used for gauging. The temperature of the room and that of water used at the time of gauging shall be from 58 degrees to 64 degrees F and no ingredient other than neat cement, and clean fresh water shall be used in making the test. The cement gauged above shall be filled without mechanical ramming into moulds provided, each mould resting on a nonporous plate until the cement has set. The mould shall be kept in a humid atmosphere for 24 hours after gauging when the briquettes shall be removed from the mould and placed in clean fresh water and allowed to remain there till required for breaking.

Procedure :—The object of the experiment is to determine the exact proportion of water that gives the maximum strength to the cement. This proportion only shall be used for purposes of standard tests. 1 ℔. of neat cement should be weighed out and specified proportions of water shall be added. If the percentage is 22 the quantity of water to be added is ·22 ℔s. i. e., 196 *cc* and so on. The mixtures shall be well mixed in a mixer and then filled into the mould with the hand. The cement shall be pressed with the fingers and when filled completely smoothened with a trowel. Repeat the above with various proportions specified. The moulds are covered with a wet cloth for 24 hours. The briquettes are removed and kept in clean water till required for test.

Observation and test:—

S. No.	Proportion.	Wt. of Cement lbs.	Sand lbs.	Water lbs.	Remarks.
1	Neat Cement.				
2	1 : 1				
3	1 : 2				
4	1 : 3				
5	1 : 4				
6	1 : 5				

EXPERIMENT NO. 26.

Tension Test on Cement mortar briquettes on Avery's Cement Testing Machine.

General:—B. S. S. states that briquettes prepared from neat cement shall be tested for tensile strength. The briquettes shall be tested for breaking at 7 days after making, 6 briquettes being taken to strike the average, which shall be taken as the tensile strength at seven days. For breaking the briquettes shall be held in strong metal jaws of the standard shape prescribed, the briquettes being slightly greased where gripped by the jaws. The load must be steadily and uniformly applied starting from zero and increasing at the rate of 100 lbs. per 12 seconds. The average breaking strength of the briquettes at seven days after gauging shall not be less than 600lbs/□″. The 28 days test has been omitted.

Note the specification about the rate of loading, since greater speed produces greater strength.

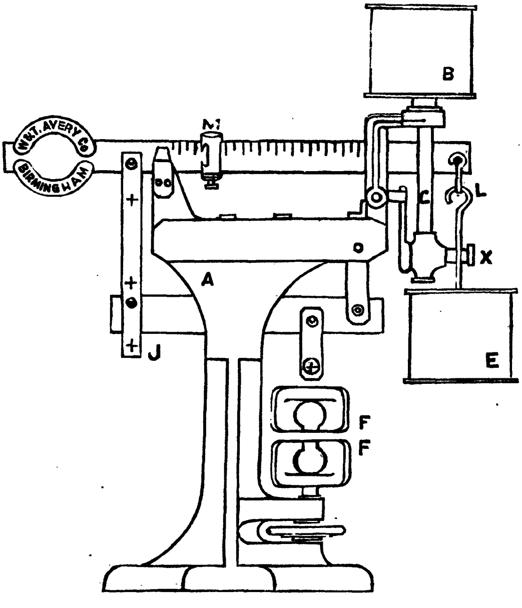


Fig. 22

The apparatus shown in figure consists of a cast iron frame A carrying a pair of compound levers. The levers are fitted with tempered steel knife edges which rest on polished concave bearings of tempered steel, making a very sensitive balance. A sliding weight for setting the levers in equilibrium is fitted to the upper lever at its left hand end. The horse shoe clamp for holding the briquettes are shaped in accordance with the B. S. S. and are sufficiently massive to need no cross stays. The upper clamp is suspended from a knife edge on the lower lever; the lower clamp is attached to the base of the column and is adjustable. There is a reservoir can B fitted on to the carrier C and having a reservoir can E (at the end of the steel yard) into which the lead shots flow from the can B.

Procedure :— The mould is opened and the specimen placed between the grips F. F. The test is commenced by raising the end of the steel yard to the top of the carrier C and turning the hand wheel G so that the steel yard just remains at the top of the carrier. Next open the sluice by means of the trigger H so that the shot from the reservoir B flows into the can E suspended from the steelyard. If the steelyard begins to fall, stop the supply of shot and raise it to the top of the carrier C again, and revolve the handwheel 'G' as before. When the specimen breaks, the steelyard in falling strikes the trigger H automatically cutting off the supply of shot.

The can containing the shot is now unhooked from the end of the steelyard and suspended at G, its weight being counterbalanced by the suspension of the counterpoise K at L. The shot that has flowed into the can E is weighed by moving the poise along the steelyard and the application of the proportional weights to the counterpoise K. The final reading of this weight will give the strain at which the specimen broke.

A screw adjustment 'X' is provided for regulating the flow of shot. It is most essential for accurate testing that the machine should stand absolutely dead level, and for this purpose 4 faces are provided underneath the steelyard on the main casting, for levelling purposes.

Observation and record :—

	Mixture	Serial No.	Load $\frac{\text{lbs}}{\square''}$	Mean
	1 : 3	1		
		2		
		3		
	1 : 4	4		
		5		
		6		
		–		
		–		
		–		
		–		

EXPERIMENT. NO. 27.

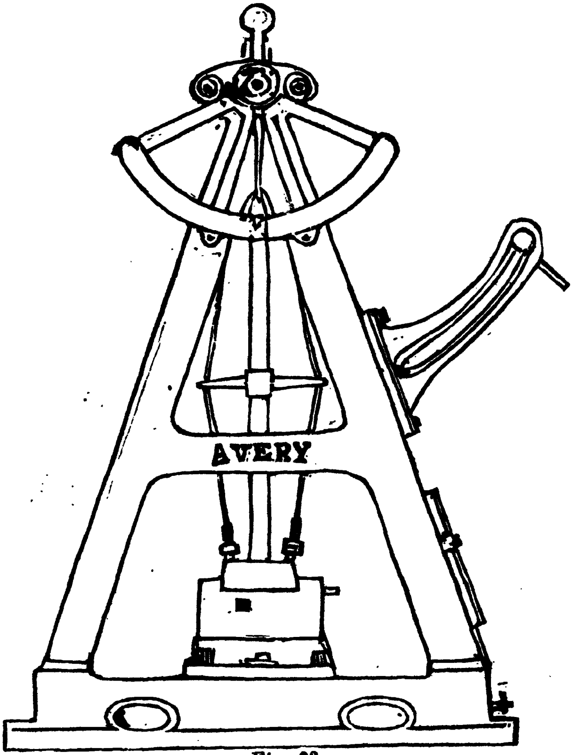
Impact Test on Izods Machine.

General:—The ordinary tensile and bending tests are no true criterion of the impact resisting qualities of the material and in all cases where a material is employed for parts subjected to shock or impact, tests should be made on samples under similar conditions. Machines devised for testing of materials under conditions of impact or shock may be roughly divided into 2 classes.

(a) Machines for breaking the given specimen at a single blow and provided with means for measuring the energy absorbed.

(b) Machine for repeated impacts for delivering a number of blows of known energy before fracturing the specimen.

The Izod machine belongs to the first type. The test is the application of a single blow to a specimen of prescribed size and shape, supported as a cantilever and having a notch cut in its striking face to ensure the effect of the blow is definitely located at a fixed distance from the point of impact. The blow is imparted to the specimen by a pendulum of prescribed weight falling through a sufficient height. In addition to indicating the toughness of a material or its resistance to shock this test may reveal the correct chemical composition or absence of necessary heat treatment.



Fig, 23.

The machine consists of a base box upon which two rigid frames of 'A' shape are erected and bolted to the base box and clamped together by means of two spacing bolts. Between the apex of these frames is a pendulum or tup mounted in ball bearings, and fitted with a hardened steel insert which strikes the specimen at a fixed distance above the gripping dies carried in an anvil secured to the base plate. A graduated quadrant and a loose pointer are fitted on to the front of the A frame, at the apex of the machine.

To calibrate the Machine :—

The trigger is set along the arm of the frame until the pendulum rod, when resting upon the bolt of the trigger, allows the pendulum pointer to indicate 120 ft. ℔. upon the right hand side of the graduated quadrant. If the trigger be released the pendulum should rise to the same height upon the opposite side as that from which it fell. This will be shown by the loose registering pointer (which will be carried forward by the pendulum) reaching the zero mark at the left hand side of the quadrant.

When the pendulum is hanging vertically, the pointer should also be registering zero. The locknut at the front of the machine should be carefully adjusted to give correct amount of pressure to the pointer.

Specimen :— The Vee notch is cut to the specified depth, this being ascertained by the notch gauge supplied. The specimen is secured between 2 Steel Vice jaws, fitted in the anvil block. A small flate gauge is supplied to ensure that the centre of the whole in the specimen is exactly level with the top of the anvil. When the machine is fixed level and the pendulum is hanging vertically (the pointer registering zeao) the specimen should be just touching the striking knife edge, and the height of the knife edge above the steel dies should be exactly 22 m. m.

To make a test :— Insert the specimen, then raise the pendulum to its full height, when the potential energy of the pendulum will be 120ft. ℔.

Place the registering pointer to 120 ft. ℔. on the left hand scale. Now release the trigger, and whereas the pendulum before ths insertion of the specimen ascended to the same height as that form which it fell, it will now rise to a less height, the actual distance depending upon the nature of the specimen being tested. From the difference between the height through which the pendulum fell before breaking the specimen and the height through which it rose after fracture, the energy expended in fracturing the material can be calculated. On the machine the quadrant is so graduated that when the loose pointer comes to rest it gives a direct reading of the impact value in ft. ℔s. In addition to this an examination of the fracture will give some information as to the nature of the naturial.

After the specimen is broken, the pendulum swings back again towards the releasing gear, and it can be caught by the hand and lowered to the rest, which is easily moved into position. This allows for the examination of the specimen, and fecilitates the removal and insertion of specimens. When the pendulum is again lifted, the rest automatically falls out of position.

Observation and Record :

Serial No.	Nature of specimen	Diameter or side	Area	Energy absorbed ft. ℔.

Experiment No. 28.

Brinell's Hardness Test on Metals on Brinell's Machine.

General :—Hardness may be defined as the resistance to penetration by other bodies. The various tests which have been devised to determine the hardness are of two classes which may be called *Indentation tests* and *Scoring* or *Scratching tests.* Indentation tests have been arranged with punches or indenting tools of various shapes and various methods of measurement have been adopted. The depth, superficial area of volume of indentation by a given static pressure or by the impact of a given weight falling through a given height, may be measured or the pressure or blow necessary to give some specific indentation may be measured. One of the objections to all indentation methods of hardness testing is the difficulty of producing the same degree of hardness in all punches or in identing tools.

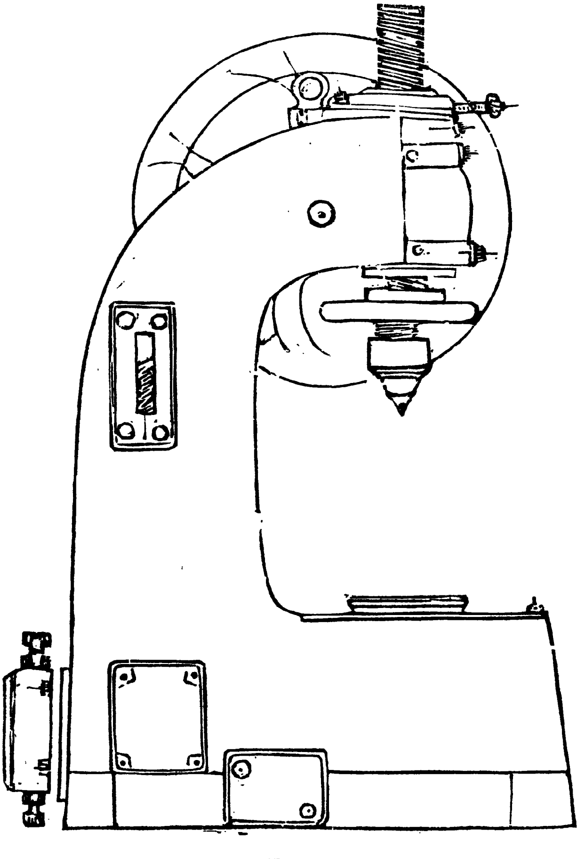


Fig. 24.

Brinell Hardness Tester :—All pointed indenting tools are likely to lose their sharpness and so Brinell used a spherical ball. The test consists of forcing a hardened steel ball of definite size into a flat surface of the material to be tested under a definite pressure and then measuring the diameter of the indentation. Brinell takes the hardness as proportional to to the area of the cavity made by a fixed pressure and size of ball. If D is the diam. of the depression, r the radius of the ball and P the total pressure, Area of the Cavity A equals $2\pi r\,(r-\sqrt{r^2-D^2/_4})$ $\therefore$ Brinell No. equals $= \dfrac{P}{2\pi r\,(r-\sqrt{r^2-D^2/_4})}$, which depends on D alone as P and r are fixed. In the standard machine P is 3000 Kgm. for hard metals and 500 for soft metals.

Procedure :— Brighten the surface of the specimen with emery paper. Place it on the platform and if of appreciable weight balance it by moving the small riders on the levers. Then place the required weight on the hangers. If the indenting ball is much above the specimen, release the clutch and bring the ball down near the surface by rotating the handwheel fixed to the screw. If the distance is small put on the clutch and rotate the big wheel at the side. Now the screw will descend slowly without rotation. Rotate till the lever becomes horizontal. Allow the load to remain for 15 seconds or 30 seconds and then work this big wheel back till the ball is off the specimen. Releasing should not be done by handwheel attached to the screw Measure the dimeter of the indentation by means of the microscope provided, at two places at right angles to one another. Refer to the tables and find the hardness number. Repeat twice for all specimens.

Calculate also the hardness Numbers (without referring to the tables) from the load, the diameter of the ball and the impression in the three cases.

Observation and record :—

Tabulate the results thus :—

Serial No.	Material of Specimen	3000 Kgms. Dr. of ball Imp.	Hardness No.	Calculated Value	500 kgm. Dr. of ball Imp.	Hardness No.	Calculated Value.
1	Hard Steel						
2	Mild Steel						
3	Cast Iron						
4	Brass						
5	Copper						

Ex :—Calculate the Brinell's Hardness No. of a piece of metal when a load of 3.000 Kgm. is used with a ball of 10 mm. and the dia. of indentation produced is 5·5 mm.

Study of Amsler Testing Machine.

General :— There are two principal types of testing machines used for testing materials in tension, compression and bending viz:—Vertical and Horizontal types These are termed according as the test bar is kept in a horizontal or vertical position When very long specimens have to be tested, the machine must be horizontal. There is a difference of action not entirely unimportant in the horizontal and vertical types. In the former, the weight of the shackles and other parts connected with the specimen acts transversely to the load applied by the machine. If not neutralised by the guides, the weight would produce straining actions not measured by the weighing apparatus. No guides can quite perfectly prevent this transverse action, though they may render it comparatively harmless. The guides themselves introduce some frictional resistance which gets measured as part of the stress. In vertical machines, on the other hand, the weight of the shackles acts in the direction of the load, and can be balanced without guides—so as not to affect the measurement of the stress. The Amsler Machine belongs to this class.

General Principle :— Oil is pumped from a reservoir into a hydraulic or pressure cylinder where it pushes up a ram which pulls up along with it a movable platform to which one end of the specimen is attached. The other end is gripped by a pair of shackles. The stress is measured not by weighing as in the case of Bucktons but by measurement of the thrust inside *the cylinder. The appliance known as the pendulum dynamometer is used* to record the pressure. The total load on the specimen at any instant is equal to the area of the ram multiplied by the pressure of oil per square inch. The oil pressure is made to act on a small piston inside a small cylinder which on moving down pulls a connecting rod attached to a pendulum, The pendulum is tilted off its vertical position so that the movement of the weight of the pendulum acting through its c. g. about the axis of suspension balances the moment of the thrust on the piston about the same axis The deflection of the pendulum will be proportional to the load applied on the specimen. In its angular motion the pendulum moves a horizontal rack which in turn rotates a pinion wheel carrying a pointer moving round a graduated circular disc. It is so graduated that a complete range of the machine is given by a complete revolution of the needle. A special feature of this machine is the device for varying the sensitiveness of the machine The length of the pendulum may be varied and the same pressure may produce a greater angular motion of the pendulum and corresponding motion of the pointer, thus producing more sensitiveness. By this means one revolution of the pointer is made to correspond to either 15, 10, 1·5, or 1 ton as the case may be.

An ingenious method allows these ranges to be reduced 10 times and the principle of the device is to allow the oil to act on a smaller ram producing a smaller load from the same pressure on the piston recorded by the dynamometer. The device consists of a differential coaxial ram working inside the bigger ram. Arrangements are made by means of which we can make the inner alone, or both to act together. The area of the inner ram alone is $\frac{1}{10}$ area of the two rams put together. Hence the ranges working with the inner ram alone becomes 1·5,1,0·5, and 0·1 T. But this device has not been ordered for use in our Laboratory.

The Oil Pump : —Oil is pumped into the cylinder from a cam pump which can be operated by an electric motor, by belt drive or by hand. Here only by electric motor) The oil as it is pumped goes along a pipe behind the dynamometer to the inlet valve from where one branch goes to the dynamometer cylinder and another to the ram. At the entrance of the oil pipe to the ram, there is a box like chamber from which connections are made to the pressure cylinder. From this chamber one pipe leads away to the release valve chamber which when opened drains away the goes oil to the reservoir. There is also another pipe which carries away the excess oil. A pipe from the top of the cylinder to the chamber, referred to above, leads the overflow oil to the chamber, should the piston be pushed by an axcess *of pressure. The inlet and release valves are placed in front of the dynamometer* and can be operated with such ease that the stress can be applied at low speeds and kept constant for a long time.

The Straining Mechanism :— This is distinctly separated from the dynamometer and pump and is connected to them only by means of oil pipes The whole mechanism is supported on a frame consisting of a pedestal supporting two vertical rods, 2" in diam. the tops of which are connected by a cross piece. Resting on this, is the hydraulic cylinder. The mode of measuring stresses in this machine requires that the pressure of the oil should be communicated to the specimen with the least possible losses due to friction. Therefore the ram of the pressure cylinder is fitted with great precision dispensing with collars and cup leathers. The small amount of play which the ram has in a cylinder allows slight percolation of the oil to take place between it and the cylinder and makes its movement easy A plate having a V slot in it such that the distance between the two parallel edges, is equal to the diameter of the inner ram, can be pushed over the two rams, and this keeps down the annular portion, and allows the smaller ram only to work.

The Moving Cradle :— Over the ram rests a crosshead from which hangs a moving cradle by means of long rods with screw threads cut on them. The moving cradle has to carry one end of the specimen. It can be brought to any desired height by working the handle wheel (provided with an endless chain) fixed to the side of the crosshead referred to above.

This works two worms engaging with the screw threads in the two supports of the cradle. The cradle itself is in the shape of a long beam. In bending experiments the specimen is kept along the length of the cradle, while in compression experiments the ends of the specimen rest on a flat piece fixed to the centre of the cradle. In performing bending experiments, the specimen as a whole being supported by the cradle is lifted while the centre of the specimen is kept depressed by a knife edge attached to the fixed crosshead upon which the pressure cylinder is crested. For compression tests the knife edge will be removed and a flat piece inserted in the lower end of the fixed crosshead. For tension experiments one end of the specimen is fixed to the grips in a lower crosshead fixed to the frame. This can also be kept at any desired height by operating a handle.

The Pendulum Dynamometer: A branch of the oil pipe going into the pressure cylinder starts from the inlet valve and passing along the front of the dynamometer frame enters a small cylinder situated behind the release valve and thence to the dynamometer cylinder. Here the oil presses on a small ram which is connected to a crosshead which in turn is connected to an upper crosshead, carrying a rod which is linked to a lever working an axle. To the end of this axle is attached a guiding piece in which the pendulum weight can slide, and can be fixed at any position by means of a set screw.

Two needles are mounted on the axles of the pinion wheel, one fixed to it and the other free on it. A projection on the latter causes the former needle to push this one also along with it, while the stress is increasing i. e., while they are moving in a clockwise direction. But when once the stress begins to decrease the pointer fixed to the axle of the pinion returns while the other remains at the maximum point recorded. This is a convenient arrangement for noting the maximum stress reached in any test.

Autographic Recorder :—This apparatus draws a stress strain or rather a load extension diagram without any readings being taken. This is done by using a rotating drum. It is necessary to give the recording pencil two motions at right angles ; one motion proportional to the load put on the specimen, and the other proportional to the extension produced by that load.

The motion proportional to the load, at right angles to the extension movement is obtained by rotating the drum E, which gives essentially the same result as moving the pencil horizontally in the opposite direction. This is obtained from the shaft which moves the weight along the beam, and so actuates the load. As this shaft rotates, it turns the pulley G which drives the pulley H by means of a wire driving a cord F. The worm wheel K is rotated by means of a shaft and working from H and so the rotation of the drum E is proportional to the movement of H and hence to the load on the specimen.

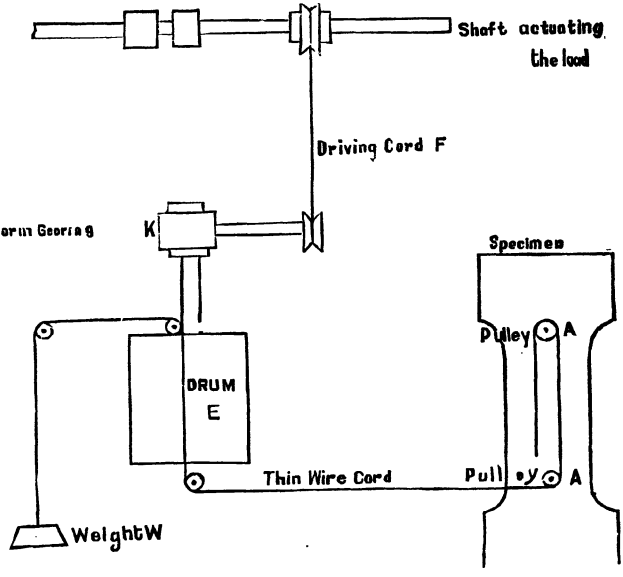


Fig. 25.

An extensometer is clamped on the test bar and transmits by means of a thin wire and cord the elongation of that part of the specimen lying between the two gauge knives, to the recording drum of the dynamometer. The extensometer is a telescopic tube carrying at each end a knife edge. At each knife edge there is a clip, by means of which the knife edge is pressed against the test bar. Attach the thread to the eyelet and lead it over the roller to the guide roller on the dynomometer. When the test bar elongates, the two parts of the tube move apart, whereby the thread runs over the roller by an amount exactly equal to the variation in the distance between the knife edges attached to the test bar. If the thread is lead over the large groove of the recording drum, the elongation of the test bar is recorded full size; if lead over the small groove it is recorded double size.

Each knife edge consists of a disc with two sharp rims, one convex and one cut out V shape. For flat test bars, the convex knife edge and for round specimens the concave parts are turned against the test piece. The eyelet to which the thread is attached is pressed against its seatings by a spring.

The extensometer is designed for an initial gauge length of 8″ but by fitting any of the interchangeable tubes with the instrument, initial gauge lengths of 6″ or 4″ between knives can be set.

The telescopic tubes are provided with a scale in inches and decimals and an index for observing the elongation during the test.

Chief advantages of this Machine:—

1. It is simple in construction, easy to operate and may be employed equally conveniently in carrying out routine work in the test house of any works.

2. It can be loaded up to the maximum capacity as often and for as long as may be desired, without any damage resulting to the mechanism owing to the absence of knife edges. They are practically indestructible and only with difficulty is it possible to put them out of order.

3. It is easily accessible from all sides, which is a great advantage for the operation as well as for the observation of the machine

4. The ram is fitted with such great precision in the cylinder that there is only a slight leakage of oil between them. This eliminates all

friction and allows of exact measurements, whereas the collars of cup leathers used in the other instruments produce friction.

5. The complete separation of the dynamometer from the Testing machine is a special feature of this machine. The load indicator is never subjected to shocks. It is very sensitive and has very little inertia unlike the levers in the other machines.

6. It is not necessary to place this machine on special foundations. On the other hand, lever machines require very heavy foundations. Amsler machine is very light and is easily transportable.

EXPERIMENT NO. 29.

Tension Test on Amslers' Machine.

General. (a) *Plain Flat Bars*:—are gripped between the wedges having serrated flat faces. The wedges are introduced into the gripping boxes provided.

(b) *Plain round Bars and wires.*—are gripped between wedges with a serrated groove. Thin wires which would not securely be held within grooves should be gripped between one grooved and one plain flat wedge or between two flat wedges.

(c) *Shouldered round bars*:—are assembled in the rings and seatings and the entire assembly is then pushed into the heads. Care must be taken to see that the seatings are well pushed home so that the axis of the test bar coincides exactly with the axis of the testing machine. When the test bar is gripped it is advisable to turn it to and fro by hand, exerting at the same time a slight tension by turning the handle. In this way the spherical seatings adapt themselves and can be properly adjusted, thus ensuring proper tensile stress on the test bar.

Note:—(1) In order to prevent the gripping wedges or rings being thrown out of the heads by the reaction of the machine at fracture of a specimen, the sheaves must be turned on the heads in such a way that the openings are closed.

(2) The upper compression plate fixed to the bottom of the cylinder crosshead may remain in its place also during tensile tests. It then serves as stop for the moving crosshead and prevents it from being pressed against the moving boltheads holding the cylinder and damaging these.

(3) The lower compression plate on the other hand must be removed during tensile tests, as it would be thrown off at fracture of the specimen and might cause damage.

Procedure:—See if the machine is in working order. Arrange the range sufficient for testing the specimen. Fix the specimen on the machine as described above. Note the least count of the machine with the above range. Take the zero reading if the pointer is not at zero or set it to zero. This is done after slightly lifting the ram from its bottom position.

First close the outlet valve. Open the inlet valve about half a turn. Now work the pump till the pendulum becomes vertical. In this position the ram has been lifted off the bottom of this cylinder and enough oil has been pumped to balance the weight of the bending bench and tension shackles so that this will give the zero position. Adjust the pointer to zero or take the zero reading. Now close the inlet valve. Fix the specimen in the two grips.

Now slowly open the inlet valve through 4 divisions. Fix the extensometer to the specimen and work the pump.

Set the pointer of the extensometer to zero. Work the pump slowly but uniformly. Note the loads corresponding to every $\frac{1}{1000}$ extension. Proceed without stopping to elastic limit taking readings. Remove the extensometer. Measure further extensions at ½ T. intervals by means of calipers. As soon as the specimen breaks, close the inlet valve. Remove the broken specimen from the grips. Then very slowly open the inlet valve so that the ram descends *slowly*. Note the maximum load.

Measurements :—Determine the yield stress, the proof stress, the ultimate tensile stress, percentage elongation, percentage reduction of area and the Young's Modulus of Elasticity.

Tabulate the readings thus :—

Load in T.	Extensometer Reading.	Extension in Ins.	Remarks.

Ex. :— *The following results were obtained in a tensile test of a piece of steel* :—

(*1*) *Dia. of cross section of specimen, 1⅛″.*

(*2*) *Gross tensile load at limit of elasticity, 18 T.*

(*3*) *Gross tensile load at rupture, 36 T.*

(*4*) *Total elongation on a length of 5″, 1·05″.*

(*5*) *Elongation at limit of Elasticity on a length of 5″, 0·0075″.*

(*6*) *Dia. of cross section at a point of fracture after rupture, 0·72″.*

Give your opinion as to the quality of the steel.

EXPERIMENT NO. 30.

Preparation of Cement and Lime Mortar Blocks.

General :— Mortar is the cementing material used for buildings. It bonds one stone or brick with another. Individual stone or brick being strong in compression, brickwork or stonework will generally fail only due to the crushing of the mortar; and as such the stronger the mortar the stronger the brick or stone work. It is thus found necessary to test mortars in compression.

Test Specimens:— For purposes of tests the larger the test specimen the closer will the results approach actual. Generally cylinders or cubes from 3″ to 9″ size are tested.

Procedure — Calculate the volumes of mortar approximately required to fill in 2 moulds or 12 test spcimens. Six should be tested after 3 days and six after 7 days. The volume of mortar required gives nearly the volume of sand required since the cement or lime only fills in the voids. Having determined the volume of sand and the corresponding weight (1 cft. of sand weighs 90 ℔s.) calculate the weight or volume of cement or lime as the case may be required for the given proportion of mortar.

Take the requisite quantity of cement and sand (sieved to pass between 20 and 30). Mix them well while dry, so that the whole mass gets a uniform colour. Add water in the given proportion, or if not given in a proportion to produce just a wet consistency. Fill in the moulds and ram them well. Level up the top neatly. Then remove the moulds carefully. Prepare mortar of another proportion and so on i. e., from 1 : 1 to 1 : 8.

If the mortar is cement mortar it will be kept in a humid atmosphere for 24 hours and then kept in water till day of test. If lime and surki, they must always be kept under a humid atmosphere and not under water.

If mortar cubes are required, individual moulds must be taken, filled in with mortar and rammed. Greatest care must be taken to ram properly. Less ramming causes weakness. Also too much or too little water produces too low a strength. So it is absolutely necessary that just sufficient and no more quantity of water be added unless the proportion is specified for experimental purposes.

EXPERIMENT NO. 31.

·Compression Test on Cement or Lime Mortar.

(Cubes or Cylinders)

General. Compression tests in Amsler Machines are made between two plates, the upper one of which is fixed to the base of the cylinder, whilst the lower one is placed on top of the movable cradle. One of these plates is provided with a spherical seating, permitting it to adjust itself to any small irregularity in the shape of the test piece. The other compression plate is rigid.

Procedure. The various blocks prepared in Experiment No. 30 are tested in this machine. The specimen is covered on both sides with a cardboard. The crushing load as indicated by the pointer in the disc is taken and the average for the different values in different cases is found.

Results. The values are tabulated as shown below and a graph drawn showing the variation of strength with the proportion of water. The % of water for maximum strength must be noted.

Proportion of Mortar.	Crushing load			Average Cr. Load T	Area of specimen Sq. in.	Crushing strength T/Sq. in.
	1	2	3			

Note :—The addition of sand to mortar decreases the strength. But the addition of surki increases the strength of mortar up to a certain limit beyond which the strength begins to fall. The addition of lime to cement for mortar has only the effect of sand to cement. It acts only as a filler.

EXPERIMENT NO. 32.

Preparation and testing the Tensile strength of Lime and combination Mortar Blocks in Avery's Cement Testing Machine.

1: ½: 1½: ., 1: 1½: 2 ., 1: 1: 1., with Kankar and Shell Limes.

General :—In most of the common works, lime surki mortar only is used. Its comparative cheapness and easy workability enables it to be used in almost all places. If surki is added to lime mortar, the mortar gets hydraulic properties and it is able to set under water, so that in irrigation works if very gret strength is not required, surki mortar only is used in preference to cement mortar. In some rare cases combination mortar is used. The addition of lime to cement only decreases the strength and the lime only acts as a filler just like sand. A certain quantity of sand is absolutely necessary for lime mortar, so that a greater surface of lime is offered for hardening. But beyond a certain proportion of sand, its addition decreases the strength of the lime mortar. Addition of surki, on the other hand increases the strength of lime mortar up to a certain limit, and beyond this, the strength decreases. The object of these tests is to have an idea of the approximate proportions for maximum strength of lime mortar.

Procedure :— The proportions given may be taken by volume. Mix the required quantity of lime and sand in the given proportion. Add sufficient water to get a good mixture. Fill in the moulds. Ram well. Keep it for 24 hours and then remove moulds.

If surki also is added it must be kept under wet cloth. If cement also is added, the briquettes must be placed in water after 24 hours.

Test the briquettes as described in experiment No. 26 for cement mortar. Great care should be taken not to overstrain the briquette initially. Also if the breaking load is very low, the flow of the shot may not be stopped automatically when the specimen breaks. Care must be taken to press the lever with the hand just when the specimen breaks. In most cases this will not be required, since the lever will act.

Observation and Record :— Tabulate the tensile stress taken (in ℔s/sq in.) by various specimens.

EXPERIMENT NO. 33.

Preparation of Cement and Lime Concrete Blocks.

Cement Concrete 1: 2: 4; Lime Surki Concrete 1: 1½: 2: 4.

Mixing Cement Concrete:— Required quantities of cement and sand are first well mixed dry. Then the proportionate volume of jelly is added and the whole mixed thoroughly. Water is then gradually added at the same time turning the mixture with the trowel. The quantity of water should be just sufficient to make the concrete to leave a stain when handled. The water used must also bear a definite proportion to the ingredients. With too little water, concrete does not pack well. With too much water it does not set well. Air bubbles must be avoided. when mixing, as these tend to decrease the strength of the concrete by forming layers round the stones of the aggregate and thus preventing proper adhesion of the cementing material. The concrete thus mixed must be used as soon as possible.

The main differences in the mixing of the two kinds of concrete, is that while cement concrete may be prepared either by mixing the ingredients dry and then adding water, or by preparing cement mortar and then adding the jelly quickly ; lime concrete should not be prepared by the first method. Lime mortar alone should be prepared first with the requisite quantity of water and then the jelly should be added and the whole thoroughtly mixed.

Test Specimens:— For testing purposes, concrete is generally prepared in cubical or cylindrical blocks, both solid and hollow. The mould is made of iron and is cubical in shape. This is in two halves which are bolted on together. Concrete is laid in with a trowel in one inch layers and well rammed. The consistency of the concrete must be such that by the time the whole cylinder is finished, water froths up to the surface. Hollow bloks are also prepared in suitable moulds supplied.

General:—In actual practice only the compressive strength of concrete is needed. But even the compressive strength varies within wide limits. The following factors affect the strength of concrete to more or less extent.

1. Proportion and quality of ingredients.
2. Method of Mixing.
3. Consolidation effected.
4. Proportion of water used.

5. Form of specimen.
6. Atmospheric conditions during hardening.
7. Time after gauging.
8 The manner and rate of applying load.

In general, it may be said that the ingredients must be proportioned so that the smaller particles fill up the voids in the larger ones. Also, as little water as possible required to produce a good consistency should be used. Concrete should not be allowed to dry after mixing, which should be thoroughly done. The greater the ramming, the greater the strength—concrete increases in strength with increase of time of curing—So also increased strength is obtained with increased rate of loading. In general, the larger the test specimen, the lower the result obtained.

Observation and Record:—Note down the proportions of the various ingredients, the % of water and the dimensions of the specimen.

EXPERIMENT NO. 34.

Compression Test on Cement and Lime Concrete Blocks.

Specimen:—The cubes of concrete prepared in Experiment No. 33 are tested. The specimen, if cement concrete, will be kept under water till required for test. Weigh the specimen and measure the dimensions of the specimen by slide calipers.

General:—Compression tests are generally made for materials such as stone, concrete, bricks (single and built up), cast iron, wood and carbon. In the case of stone and concrete, the shape of the specimen is usually a cube and the brick piers are built square in section and 4 or 5 brick layers high. The compressive strength of a body is a quantity depending much upon the ratio of the length of the specimen to its cross sectional area. In actual practice, the materials mentioned above are mostly used in other forms than cubes. Hence, a more accurate idea of the strength of the material can be got, if these forms are given to the specimen.

Procedure:—The purpose of the compression seating is to ensure axial loading, if the faces of the specimen are not parallel. First mix some Plaster of Paris to a semi-liquid consistency. Spread this on a piece of cardboard ¼″ thick and large enough to hold the specimen. Plaster of Paris should be spread at least ¼″ thick. The specimen is gently placed over this and lightly pressed. A second pad similarly treated is placed on the top of the cylinder and lightly tapped. The superfluous paste coming out is removed. The object of Plaster of Paris is to secure a uniformity of of thrust on the surfaces of the specimen. If the specimen is laid bare for testing, owing to rough and uneven surface, the straining crosshead will touch it at points and not on the whole surface, thus preventing a uniform distribution of the load applied.

The specimen is tested as in Experiment No. 31.

Observation and Record:—Tabulate the results thus:

No.	Length of Specimen.	Area of specimen.	Volume of specimen.	Wt./Vol.	Load at crack.		Maximum load		Remarks.
					Load T.	T/□" Stress	Load Tons.	Stress T/□"	

Note:—The method of failure in concrete is peculiar. The sides first begin to develop vertical cracks, and gradually flake off leaving in the end a solid, resembling more or less roughly two square pyramids joined at the apices and standing upon one another.

The plane of rupture is approximately at 45 degrees where the maximum shear occurs.

EXPERIMENT NO. 35.

Effect of Repetition of Stress on M. S. Rods and raising Elastic Limit.

General. If a bar after loading beyond the elastic limit is released and allowed to rest for some time, it recovers practically the set previously taken, and if the elastic limit is again determined by applying load in some cases it is found to be raised not only up to but even beyond the load previously taken. The material is not only nearly perfect in elasticity, in the reimposition of the load up to the original load, but goes even to a higher load.

Procedure. Inspect the machine and see if it is in proper order. Attach a ½″ M. S. rod with gauge points 8″ and 10″ marked on it, to the machine. Fix the extensometer and take the string from it to the autographic recorder. Attach a piece of paper round the drum to get the graph. Load gradually without stopping. If working of the pump is stopped, only a serrated curve will be obtained. Load must be applied uniformly. Pass the elastic limit and go about ½ T. beyond. Then unload the specimen by releasing the outlet *slowly.* Wait for five minutes and again apply load and proceed up to a load ½ T beyond the previous load. Release the pressure and repeat about 4 or 5 times and finally get the breaking load.

Take a fresh specimen of the same kind and apply load gradually till the breaking point. Note the breaking load.

Wohler's Laws:—The most important deductions from these experiments are:

1. That the resistance to fracture under fluctuating stresses depends upon certain limits on the range of fluctuation of stress, i. e. upon the algebraic difference between the maximum and minimum stress, rather than upon the maximum stress; and

2. That the reversed stresses (tensile and compressive) much below the static breaking stress, and even well within the ordinary elastic limit, are sufficient to cause fracture if repeated a great number of times.

General. The number of repetitions of loading the bar will be diminishing with increased range of variation of stress. Further, it is very striking how regularly progressive the diminutions of the number of repetetions is as the range is increased. It is impossible not to conclude that, whatever the cause of decreased life of the bar be, it is a cause which acts continuously, altering in some way the structure of the bar.

Whatever the alteration produced by repetition may be, it certainly does not appear to be a loss of strength. In certain cases flaws or fissures have been found to be present in bars subject to so many repetitions of load that they were on the point of breaking. It is at least conceivable that repetition of stress picks out sections of weakness in the bar, and that the deterioration is almost confined to such planes; the deterioration may be primarily a loss of power of yielding in the particles near the plane of weakness, and not a loss of tenacity. Such a loss of ductility at a section might well show itself in a rapidly spreading fissure.

Ex:—A member in a steel girder bridge carries a continuous D. L. tension of 9 T. due to the weight of the bridge, and is subjected to traffic loads varying from 15 T. tensile to 4 T. compressive. Assuming a safe static stress of 7 T/□″., what section would be necessary for this member?

EXPERIMENT NO. 36.

Compression and Transverse Tests on Bricks, Brick Columns and Stones.

General :— Individual bricks are generally very much stronger than the columns made from them. Hence tests on brick columns are more often made than the tests on bricks, which tests are not of much practical importance.

When the distribution of stress is not uniform for any reason on a test piece under compression, the yielding of the test piece under pressure tends to increase the irregular distribution of stress rather than to decrease it. In the case of a column under compression, if there is at any stage an irregularity in the intensity of stress, the side that has the greater stress yields more readily and the resulting thrust is obviously nearer the side which has the greater stress with the result that the irregularity is increased. To ensure axial loading spherical compression seating is provided and to get uniformity of pressure Plaster of Paris is laid at top and bottom of specimen, on which card board pieces are placed.

Procedure :— Measure the dimensions of the specimen by means of calipers. Wiegh it carefully. Mix some Plaster of Paris and water to a semi liquid consistency and then lay it on a piece of cardboard larger than the specimen. Place the specimen on the plaster and then place another piece of cardboard on it and press it. The whole is then placed on the testing machine. Slightly add load and wait till the Plaster of Paris sets completely. Apply the load gradually and note the crushing load as indicated by the pointer, just when the vertical cracks appear and also when the specimen finally crushes.

Tabulate the results thus :—

Serial No.	Length	Breadth	Depth	Area	Wt : ℔.	Load at 1st Crack.		Crushing load		Remarks.
						Load	Stress T/□"	Load	Stress T/□"	

Brick Tests :— Bricks are tested for strength by compression. The brick is in the shape of two half bricks superimposed and united with each other by a thin layer of Portland Cement. The transverse test is believed to be a valuable test of its building properties. The bricks shall be placed in a flat-wise position with the frog, if present, uppermost, upon self-aligning round supports ¾″ in radius, after having been soaked previously for 24 hours in water. The distance between the centre lines of the two supports shall be 7″, and the load shall be applied at mid-span by a similar bar of ¾″ radius.

The modulus of rupture in ℔/□″ shall be calculated from the following formula.

$R = \frac{Wl}{4} \div \frac{1}{6} bd^2 = \frac{3}{2} \frac{Wl}{bd^2}$ where W equals central load, l is the span in inches, b the breadth in inches and d the depth in inches.

EXPERIMENT NO. 37.

Compression Test on Wood—Parallel to grain.

General :—The compressive strength of timber is useful not only in designing timber compression members in a structure but also according to Prof : Bauschinger in determining the quality of the timber and the influence of the seasoning, the time of felling and other circumstances of its growth, as the tests are easily made and the results trustworthy. The tests must be made at a standard dryness. The specimens are rectangular prisms 2″ × 2″ × 8″. A crushing test of short blocks in the direction of the grain, offers the most reliable characteristic test of a quality of a sample of timber. Failure generally occurs by local buckling of the fibres over the whole of an internal surface inclined to the direction of pressure.

Procedure :—Note the dimensions of the specimen. Note that the ends of the test piece should be smooth, parallel and normal to the axis. Apply the load gradually to produce a constant rate of strain. Record the results thus :—

Load.	Extensometer reading.	Difference.

Determine (a) Compressive stress at limit of proportionality
(b) Crushing strength at maximum load and
(c) Modulus of Elasticity.

EXPERIMENT. NO. 38.

Compression test on wood—Perpendicular to grain.

General: The crushing strength of timber across grain is much smaller than along it. There is no definite point of failure and some authorities take 3 % of indentation as a limit of allowable strain and 15 % as failure of the piece. Dehra Dun Research Institute in its pamphlet takes $\frac{1''}{10}$ compression on an area of 2″×2″.

The test piece shall be a cube of 2″. The test shall be carried out in both the radial and tangential directions The load compression curve should be plotted to the point when the compression of the test piece reaches 0·1″. Should a definite maximum load be reached before this point in compression, this maximum with its associated strain shall be recorded.

Procedure:—Measure the dimensions of the specimen. Apply the load and note the compression for each load. Record the results as in experiment No. 37.

Determine (a) Compressive stress at limit of proportionality

(b) Compressive stress at compression of 0·1″ (strain 0·05)

(c) Crushing strength at maximum load

State the direction of loading, either radial or tangential.

EXPERIMENT NO. 39.

Bending Test on Wood—Central Loading.

General :—We have seen how timber is tested in tension and how the errors of experiment and other considerations such as the peculiar structure of timbers in general, make the tension test not a standard one. Bending tests are generally found to give better and more uniform results and hence they are prescribed as standard tests for wood.

Specifications issued by the Forest Research Institute Dehra Dun, require that a beam 2″ × 2″ × 30″ should be tested by a central load on a span of 28″ the loading being done at a uniform rate of 0·1″ per minute.

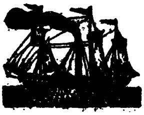
B. S. S. specifies either this method or testing a beam 2″ × 2″ × 40″, on a span of 36″ with 2 equal loads applied at a distance of 6″ from either end (called the 4 point loading method). For comparison of species of timber the central loading method is sufficiently accurate. When however, data is required which can be used with reliance in actual stress calculations, the 4 point method shall be employed since only by this method is a beam subjected to a uniform bending stress over a considerable portion of its length, and average values of E and modulus of rupture obtained.

Procedure :—The dimensions of the specimen are noted. Introduce the lower end supports and fix them at the desired distance apart, to the transverse beam by tightening the nuts. The distance apart of the end supports from centre to centre can be read on a division stamped on the beam. The test piece shall be supported at the ends in such a way that it will be quite free to follow the bending action and will not be restrained by friction which would tend to introduce longitudinal stress.

The middle support for transverse test has some small play in the vertical direction. Wheh not loaded, it is pressed downwards by a spring. As long as the middle support is in its lowest position, the brake is applied and the deflection indicator disc can be rotated only by overcoming a comparatively great friction. Immediately the middle tool is slightly raised (which is the case at the moment the transverse specimen begins to be loaded) the brake is released and the dial of the deflection indicator is free to rotate. Immediately the specimen fractures, the spring on the middle support causes the brake on the disc to be applied. The disc is at once prevented from rotating in either sense, and the maximum deflection undergone by the test piece at the moment of fracture can be noted.

Tabulate the values of load and deflection. Draw a graph showing the relation between the two. Note the value of the load at the limit of proportionality and determine the value of the modulus of elasticity.

Ex:—A timber beam 8 ft. span was tested by bending with central loading. The beam was 5·04" deep and 3·62" wide. The deflection was observed to be 1·45" at the breaking load of 2·52 T. Calculate the 'E' value for the timber and also the modulus of rupture.



EXPERIMENT NO. 40.

Impact test on wood.

General :—Examine the test piece—Note the steel plate provided to protect the specimen. Make a dimensioned sketch of the specimen.

B. S. S. specifies either (a) Applying the load at the centre of the test piece by the impact of a weight (tup) falling freely from successive heights increasing by regular increments, until either complete failure or a deflection of 6″ has been obtained or (b) A notched bar test (as in the Izod Impact Machine.)

Procedure. The notched test piece, the sides of which are cut radially and tangentially, shall be broken in the Izod Machine (just in the same way as with other specimens in Experiment No. 27) the blow being applied in the tangential direction by the swinging tup. Note the energy expended in fracturing the specimen.

EXPERIMENT NO. 41.

Hardness of Wood. (Janka Indentation Test.)

General :—The test piece shall be 6″ long and shall be of square section 2″×2″, cut radially and tangentially. The test requires the determination of the load necessary to force into the test piece, to a depth of 0·222″, the hemispherical end of a steel bar 0·444±0·002″ in diameter.

The determination shall be carried out upon the radial, tangential and both end faces. Two determinations shall be carried out upon a radial surface, two upon a tangential surface, and one on each of the end surfaces. The radial and tangential surfaces chosen for the test shall be those which most closely approach the true radial and tangential conditions.

Procedure. The Janka Hardness Tool is fixed to the upper gripping head and the specimen to be tested is placed on the lower compression plate. The Amsler Janka tool has a spherical punch of exactly the specified size. Around the punch proper there is a tube which permits of determining in a very convenient way the exact moment when the spherical head of the punch has penetrated the wood up to the equator of the sphere. The process of forcing the Janka tool into the wood must take place slowly. When the indicating tube is nearing the face of the specimen, the tube ought to be moved slowly to and fro by means of the pin attached to its side, whereby the moment the tube touches the specimen can be accurately determined, friction being set up between specimen and tube.

Record the results.

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